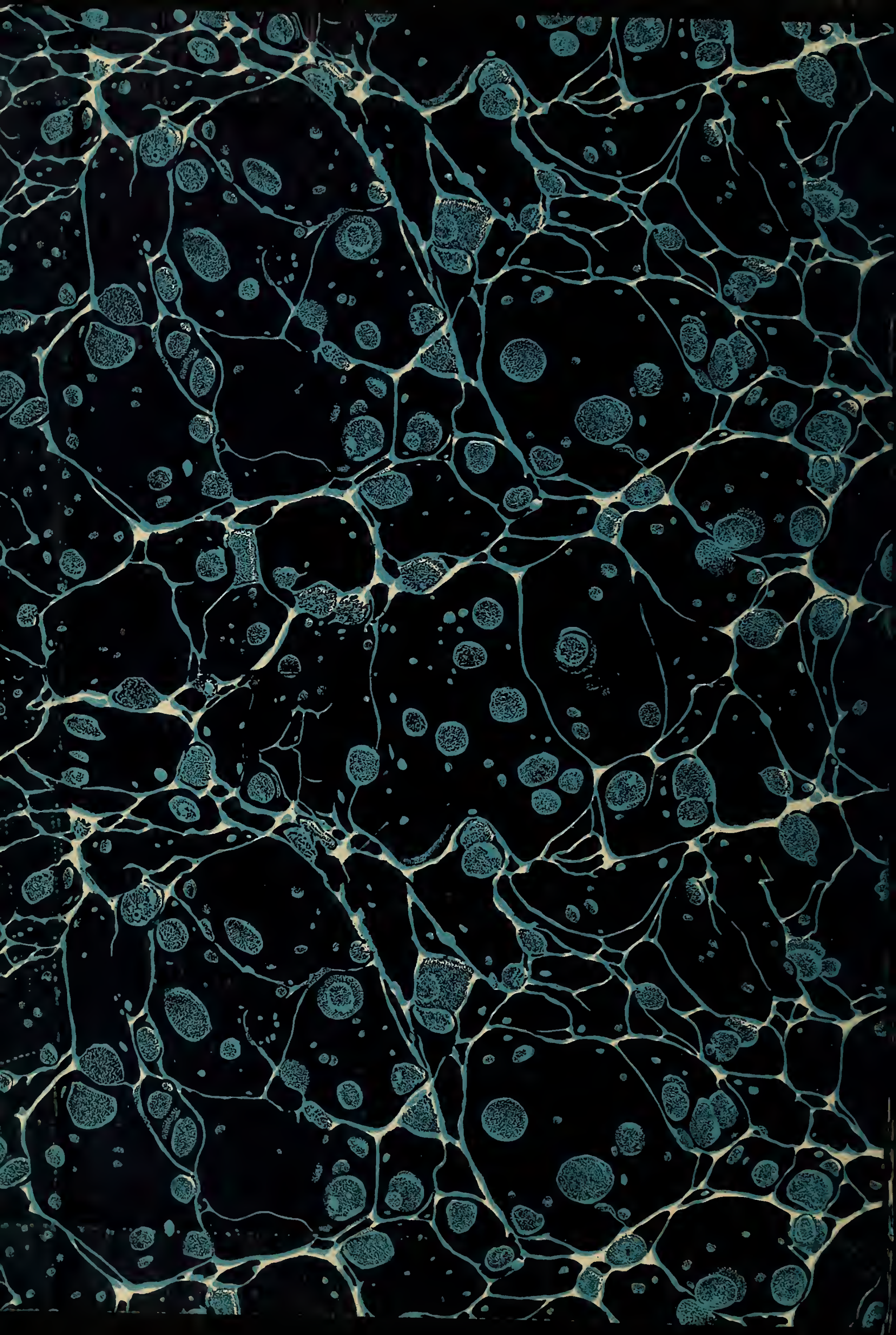
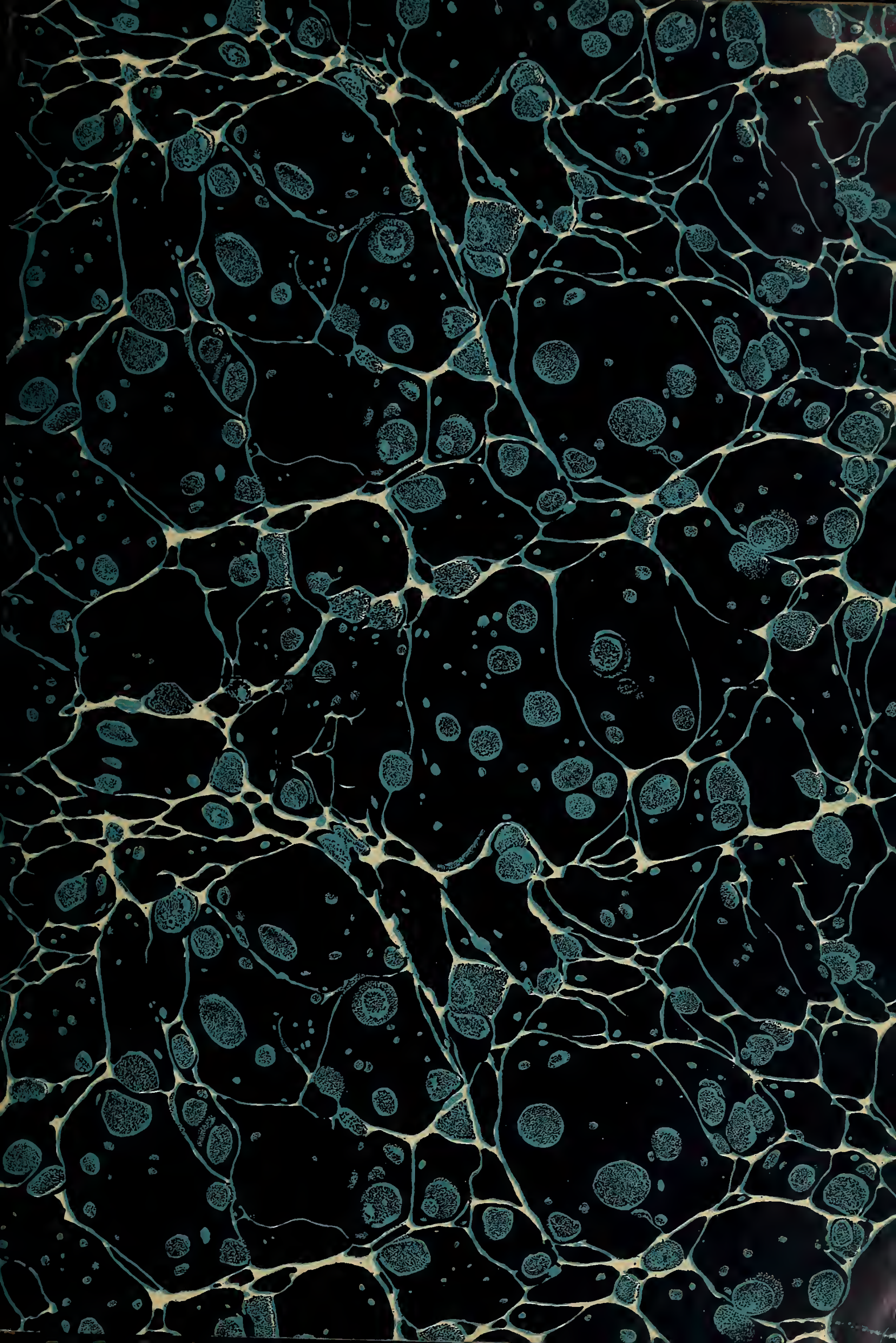
A11102 163155

NAT'L INST OF STANDARDS & TECH R.I.C.

A11102163155

/Technologic papers of the Bureau of Sta
T1 .U4 V139-151;1919-1920 C.1 NBS-PUB-C





DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 150

PHYSICAL TESTS OF MOTOR-TRUCK WHEELS

BY

CHARLES P. HOFFMANN, Assistant Engineer Physicist
Bureau of Standards

ISSUED MARCH 17, 1920

PRICE, 15 CENTS
Sold by the Superintendent of Documents, Government Printing Office,
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 150

PHYSICAL TESTS OF MOTOR-TRUCK WHEELS

BY

CHARLES P. HOFFMANN, Assistant Engineer Physicist
Bureau of Standards

ISSUED MARCH 17, 1920

PRICE, 15 CENTS
Sold by the Superintendent of Documents, Government Printing Office,
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

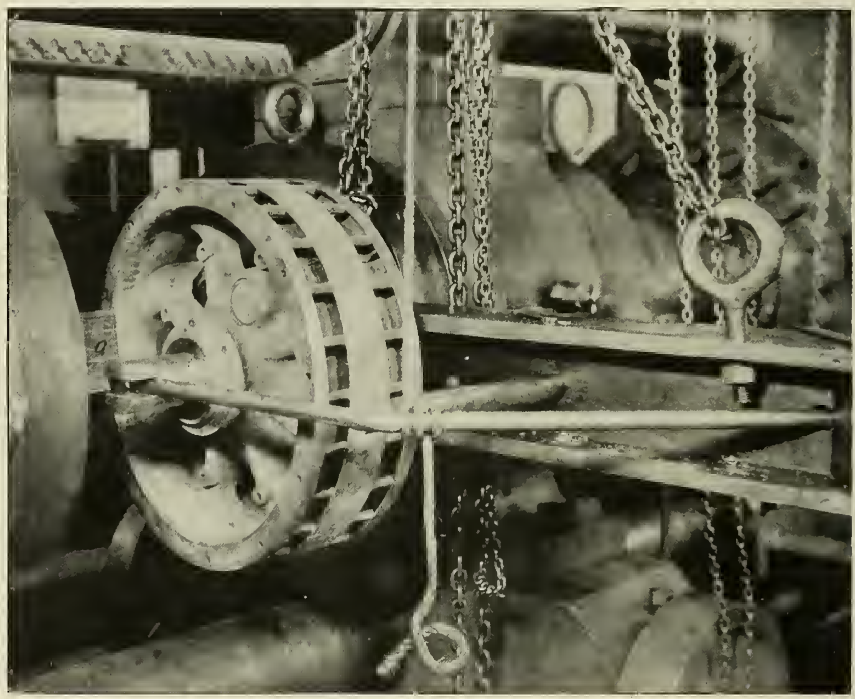


FIG. 3.—*Side-thrust test*

PHYSICAL TESTS OF MOTOR-TRUCK WHEELS

By Charles P. Hoffmann

CONTENTS

Page
I. Introduction 3
II. Wheel requirements 4
III. List of wheels tested 5
IV. Preparation of the wheels for test 5
V. Radial-compression test 6
VI. Side-thrust test 10
VII. Distribution of stress in wheel 13
  1. Stresses in rim of wheel 16
  2. Stresses in hub of wheel 18
  3. Stresses in spokes of wheel 18
VIII. Conclusions 18
IX. Summary sheets and curves 19

I. INTRODUCTION

In designing Class B military trucks, it was found desirable to develop a metal wheel having the good qualities of all the wheels on the market. No comparative values were available, however, and there was no time for service tests. The Bureau of Standards was therefore called on to make laboratory tests.

Cast steel, pressed steel, wrought iron, and wooden wheels were submitted by motor-truck wheel manufacturers and subjected to radial compression and side thrust or skid tests.

In the meantime the representatives of the companies interested, in cooperation with the Quartermaster's Department of the United States Army, designed a cast-steel wheel which thev called the "Composite wheel."

Samples of these wheels were cast and were sent to the Bureau of Standards where they were tested in the same way as the other wheels. Certain alterations in design were found to be desirable. These were made and new wheels cast which were in turn tested. They proved to be satisfactory and were accepted by the Quartermaster's Department.

II. WHEEL REQUIREMENTS

The requirements listed below were considered essential in a wheel, and the tests were so conducted that information concerning these requirements might be obtained.

(*a*) Each wheel should be strong enough to support its proportionate share of the weight of the truck and of the maximum load which the truck is designed to carry.

(*b*) Each wheel should be strong enough to resist suddenly applied loads and resilient enough to absorb a large part of the shock.

(*c*) The circumference of the wheel should remain approximately circular.

(*d*) The wheel should be capable of sustaining stresses due to side thrust. These may be introduced by skidding, by turning, or by running on roadways which are crowned or have a side slope.

There should be no joints or bolts that will be loosened by radial compression, side thrust, vibration, shock, or climatic conditions.

The weight of the wheel should be as low as possible without reducing the strength of the wheel below that of the rest of the truck.

III. LIST OF WHEELS TESTED

The following wheels were submitted for test:

TABLE 1

[Unless otherwise noted the wheels were tested without tires, bearings, or brake bands. The weights listed are the weights of the wheels as tested. The dimensions given in the description are the dimensions of the wheel fitted with a tire]

Wheel No.	Description	Weight in pounds
1	Rear wheel, 36 by 10 inches; wooden wheel; 14 spokes	252
2	Front wheel, 36 by 5 inches; cast-steel disk; box rim	169
3	Rear wheel, 36 by 10 inches; cast-steel disk; box rim	268
[a]4	Front wheel, 40 by 6 inches; pressed-steel corrugated web; channel iron rim	181
[a]5	Rear wheel, 40 by 12 inches; pressed-steel corrugated web; channel iron rim	354
[a]6	Rear wheel, 36 by 6 inches; cast steel; 8 +spokes; brake band cast on wheel	215
7	Front wheel, 36 by 5 inches; cast steel; 8 U spokes; box rim	134
8	Rear wheel, 36 by 10 inches; cast steel; 8 U spokes; box rim	274
9	Front wheel, 36 by 5 inches; cast steel; 7 U spokes; box rim	136
10	Rear wheel, 36 by 10 inches; cast steel; 7 U spokes; box rim	321
11	Front wheel, 36 by 5 inches; cast steel; 5 hollow spokes; box rim	144
12	Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; box rim	130
13	Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; box rim	286
14	Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design	132
15	Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design	249
16	Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design	120
17	Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design	273
18	Rear wheel, 40 by 10 inches; cast steel; 7 hollow spokes; composite design	325
19	Rear wheel, 40 by 12 inches; cast steel; 7 hollow spokes; composite design	325
20	Front wheel, 36 by 5 inches; malleable iron; 7 hollow spokes; composite design	141
21	Rear wheel, 40 by 10 inches; malleable iron; 7 hollow spokes; composite design	288

[a] Submitted by Ordnance Department, U. S. Army.

IV. PREPARATION OF THE WHEELS FOR TEST

The wheels submitted were all without tires and in most cases were without bearings or brake bands. Where brake bands were attached they formed an integral part of the wheel and were not removed before the wheel was tested. All bearings were removed and brass bushings substituted. The contact area between the brass bushing and the hub was made equal to that between the bearing and the hub.

All wheels were fitted with these brass bushings to make possible the use of a 4-inch axle for the rear wheels and a 3½-inch axle for the front wheels.

Holes were drilled at four points, 90° apart on the edge of the rim of each wheel, so that dial gages, used for measuring the deformation of the wheel under radial stress, could be fastened to the wheel.

TESTING MACHINE USED.—The Bureau of Standards Emery hy draulic testing machine, having a capacity of 2 300 000 pounds, was used for both the radial-compression and the side-thrust tests.

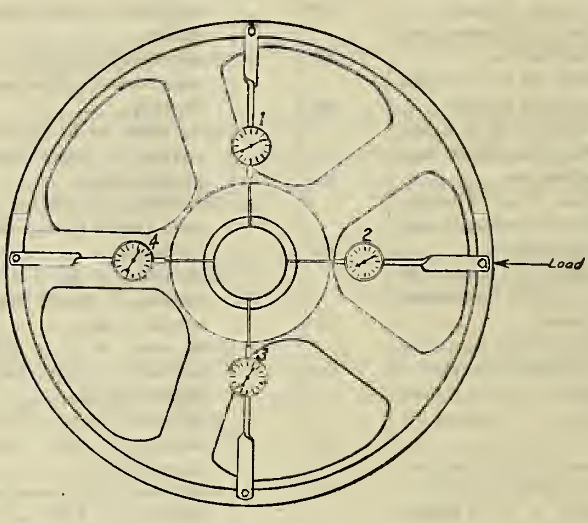


FIG. 2.—*Location of dial gages for radial-compression tests*

V. RADIAL-COMPRESSION TEST

For the radial-compression test the wheel was placed on a short axle (*a*) as shown in Fig. 1. This axle was supported on both sides of the wheel by bearing blocks (*b*).

Load was then applied through a block at the rim. This block distributed the load over the full width of the rim and along an arc of 6 inches. The wheel was placed so that the load was applied to a section of the rim between spokes.

The deformation of the wheel under load was measured at points 1, 2, 3, and 4. These points were on the edge of the rim of the wheel and 90° apart, No. 2 being at the point of application of load. Ames dials were adjusted as shown in Fig. 2, and the deformations measured between the axle and the rim of the wheel.

These measurements were made at various loads as the load was increased from 1000 pounds to the maximum load recorded

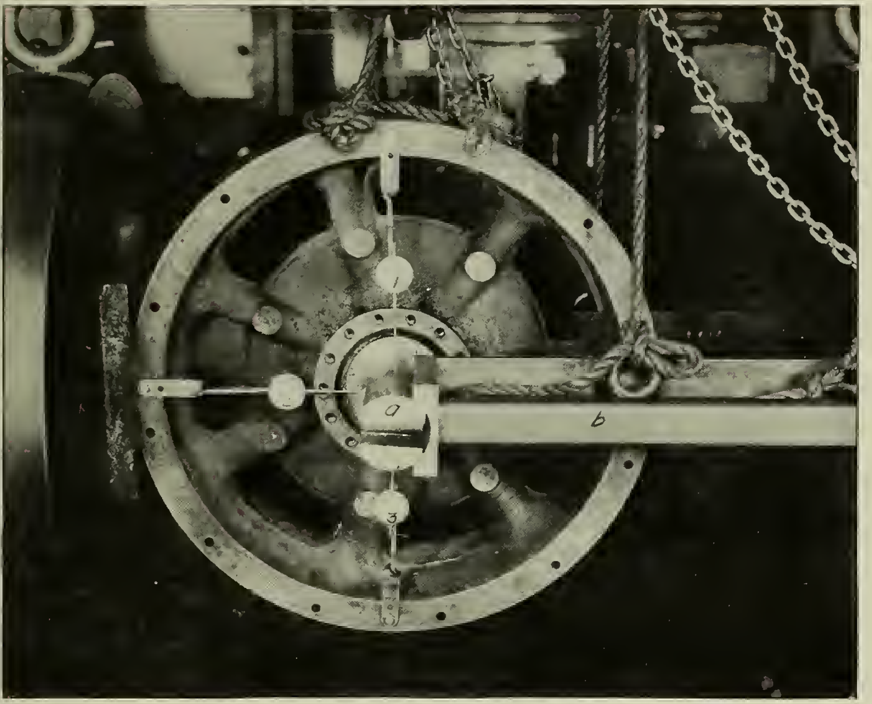


FIG. 1.—*Radial-compression test*

in Table 2. The data obtained from these tests are shown plotted as load-deformation curves.

In Table 2 are recorded the proportional limit of the wheel, as indicated by the measurements taken at the point of application of load; the maximum applied load; the deformation at maximum load; the permanent set due to stressing the wheel to the maximum load· and the slope of the load-deformation curves.

TABLE 2.—Radial Compression

Wheel No.	Proportional limit at load in pounds	Maximum applied load in pounds	Deformation at maximum load in pounds	Permanent set at maximum load in pounds	Slope of curve at load, 1000 pounds per inch
1	38 000	60 000	0.1062	0.0336	826 000
2	31 000	60 000	.0359	.0187	2 450 000
3	50 000	100 000	.0881	.0261	1 891 000
4	34 000	60 000	.0564	.0072	1 238 000
5	85 000	[a] 105 000	.1631	.0428	715 000
6	31 000	75 000	.0847	.0291	1 875 000
7	32 500	50 000	.0490	.0135	1 363 000
8	50 000	100 000	.0610	.0103	2 000 000
9	35 500	60 000	.1287	.0791	667 000
10	77 000	120 000	.1250	.0537	1 316 000
11	32 000	60 000	.0695	.0311	1 160 000
12	40 000	60 000	.0645	.0220	1 333 000
13	20 000	100 000	.0513	.0113	6 060 000
14	26 000	60 000	.1135	.0687	1 300 000
15	75 000	120 000	.0874	.0318	2 320 000
16	44 000	60 000	.0744	.0323	917 000
17	71 500	120 000	.1586	.0831	1 250 000
18	46 000	120 000	.1230	.0676	1 968 000
19	41 000	100 000	.1555	.1100	1 836 000
20	43 500	60 000	.0741	.0271	926 000
21	64 000	120 000	.1361	.0715	1 818 000

[a] Crack developed along rim of wheel where the two channels, of which the rim is formed, were welded.

The elastic resiliencies of the wheels have been computed for points Nos. 1, 2, 3, and 4 and recorded in Table 3. The area under the load-deformation curve from zero load to the proportional limit was here considered. In Table 3 will also be found the elastic resiliencies at load, per pound of metal in wheel.

TABLE 3.—Radial Compression—Elastic Resiliencies

[Area under load-deformation curves from zero to proportional limit]

Wheel No.	No. 2 at load in inch-pounds	No. 1 90° from load in inch-pounds	No. 4 180° from load in inch-pounds	No. 3 270° from load in inch-pounds	At load per pound of metal in wheel in inch-pounds
1	875		280	352	3.47
2	202				1.20
3	660	128	715	447	2.46
4	467				2.58
5	5050		725		14.3
6	257				1.2
7	387				2.89
8	625				2.28
9	1047	119		150	7.70
10	2250				7.00
11	441				3.06
12	600				4.6
13	33		390		.1
14	260				1.97
15	1210		880		4.86
16	1056				8.80
17	2090	640	319	630	7.65
18	538				1.68
19	436	195		94	1.34
20	1131				8.02
21	1128		450	255	3.91

The proportional limit of a wheel is of importance not only because the rate of deformation does not remain constant beyond that point, but also because the wheel becomes permanently deformed if higher stresses are applied. Unless the yield point of the wheel has been reached, this permanent deformation in most cases is small and does not render the wheel unfit for further use. Note that the load-deformation curve above the proportional limit usually deviates but little from the line drawn through the points below the proportional limit. The maximum load applied to the wheels is not the ultimate or breaking load.

In general, only one front and one rear wheel of each type were submitted, and it was necessary to perform both the radial-compression and the side-thrust tests on the same wheel. No attempt was made, therefore, to break the wheel in the compression test. The load was increased, however, until the wheel had been stressed well beyond its proportional limit.

The slope of the load-deformation curve is an index of the stiffness of the wheel, a high value indicating a wheel which deforms but little for all loads below the proportional limit.

Recorded in Table 4 are the resiliences for various loads. These were computed from the curve of deformation for the point where the load was applied.

TABLE 4.—Radial Compression—Resiliencies at Low Loads

[Area under curve of deformations at load]

Wheel No.	2000 pounds in inch-pounds	4000 pounds in inch-pounds	6000 pounds in inch-pounds	8000 pounds in inch-pounds	10 000 pounds in inch-pounds	12 000 pounds in inch-pounds	14 000 pounds in inch-pounds	16 000 pounds in inch-pounds	18 000 pounds in inch-pounds	20 000 pounds in inch-pounds
1	2	10	22	39	61	87	118	155	196	242
2	1	3	7	13	20	29	40	52	66	82
3	1	4	10	17	26	38	52	68	86	106
4	2	7	15	26	40	58	79	103	131	162
5	4	12	30	54	80	108	147	208	261	330
6	1	4	10	17	27	38	52	68	86	107
7	2	6	13	24	37	53	72	94	119	147
8	1	4	9	16	25	36	49	64	81	100
9	5	18	36	64	95	138	182	240	297	350
10	5	17	39	64	95	132	168	208	261	310
11	2	7	16	28	43	62	84	110	140	173
12	2	6	14	24	38	54	74	96	122	150
13	....	1	3	5	8	12	16	21	27	33
14	2	6	14	25	39	55	75	98	125	154
15	1	4	8	14	22	31	42	55	70	86
16	2	9	20	35	55	79	107	140	177	218
17	2	6	14	26	40	58	78	102	130	160
18	1	4	9	16	26	37	50	65	82	102
19	1	4	10	17	27	39	53	70	88	109
20	4	16	33	56	80	108	140	176	221	270
21	1	4	10	18	28	40	54	70	89	110

The elastic resiliences recorded in Table 3 afford another means of comparison. They should not be used, however, without at the same time carefully considering the other qualities of the wheel. Large elastic resiliency is desirable, but it may be large only because of the high proportional limit of the wheel and not because of large elastic deformation. In such cases the resiliency would be small at the loads to which the wheel is ordinarily subjected. The resiliencies at low loads were therefore computed. These resiliencies at low loads may or may not be a proportional part of the total elastic resiliency. In many cases the slope of the load-deformation curve is not a constant at low loads. This is probably due to strains being localized at first and the wheel not acting as a unit. There may also have been some movement necessary to bring the axle and bushings to a firm bearing. This movement would be recorded as deformation in the wheel because the measurements were made between the rim and the axle.

VI. SIDE-THRUST TEST

Each wheel was subjected to a side-thrust or skid test after it had been tested in radial compression.

The wheel was placed on the same axle as in the radial-compression test. As shown in Fig. 3 (frontispiece) one end of the axle was passed through a 1⅛-inch plate and then through the web of an 8½-inch, 90½-pound Bethlehem H beam to which the plate was fastened. The other end was tied back to the H beam with a 1¼-inch round bar. In this manner an effort was made to hold the axle rigidly, with its axis perpendicular to the side of the H beam, while load was applied to a section of the side of the rim of the wheel.

The wheel, mounted on the H beam, was then placed in the testing machine. The side of the H beam was supported by one head of the machine and the axis of the axle was parallel to the axis of the testing machine and, therefore, parallel to the direction of the applied load. This load was applied to the side of the rim of the wheel at point (*a*) through a block 6 inches wide. The wheel was so placed that the point of application of load was between spokes and approximately 90° from the point at which the stress had been applied in the radial-compression test. To measure the deformation of the wheel under load, Ames dials were fastened between the H beam and the side of the rim of the wheel at the point where the load was to be applied, and at a point diametrically opposite.

In this test the wheels were loaded to destruction.

Load-deflection curves were plotted, and are shown with the radial-compression curves.

In Table 5 are listed the proportional limits, the ultimate strengths, and the slopes of the curves.

TABLE 5.—Side Thrust

Wheel No.	Proportional limit at load in pounds	Ultimate load in pounds	Slope of curve at load, 1000 pounds per inch	Wheel No.	Proportional limit at load in pounds	Ultimate load in pounds	Slope of curve at load, 1000 pounds per inch
1	18 000	43 700	45 200	12	16 500	49 200	74 800
2	12 000	48 100	54 000	13	38 000	101 000	179 000
3	36 500	75 500	131 300	14	10 500	34 000	63 700
4	6 000	19 000	38 500	15	37 500	68 000	107 100
5	10 000	25 000	45 200	16	14 000	30 200	43 000
6	15 500	54 000	101 300	17	40 000	60 600	104 000
7	13 000	31 100	52 500	18	35 000	82 300	93 200
8	34 500	65 000	131 500	19	31 000	59 300	67 100
9	7 500	26 700	36 400	20	12 500	25 300	45 400
10	35 000	81 700	125 000	21	28 000	55 400	69 600
11	13 000	39 300	58 100				

The elastic resiliencies and the elastic resiliencies per pound of metal in wheel loads are recorded in Table 6.

TABLE 6.—Side Thrust—Resiliencies at Low Loads

[Area under load-deformation curve from zero to proportional limit]

Wheel No.	At load in inch-pounds	180° from load in inch-pounds	At load per pound of metal in wheel in inch-pounds	Wheel No.	At load in inch-pounds	180° from load in inch-pounds	At load per pound of metal in wheel in inch-pounds
1	3185	1800	12.65	12	1820	1480	14.00
2	1333	980	7.90	13	4040	5170	14.20
3	5060	2640	18.90	14	865	330	6.55
4	468	575	2.58	15	6550	6480	26.30
5	1108	618	3.15	16	2280	700	19.00
6	1185	1470	5.51	17	7680	850	20.30
7	1610	595	12.00	18	6560	4900	20.20
8	4520	2880	16.50	19	7160	7700	22.00
9	772	413	5.67	20	1718	310	12.20
10	5440	4100	16.90	21	7280	....	25.30
11	1460	1680	10.10				

The resiliencies for various loads were computed from the curve of deflection at the point of application of load and are recorded in Table 7.

TABLE 7.—Side Thrust—Resiliencies at Low Loads

[Area under curve of deformation at load]

Wheel No.	2000 pounds in inch-pounds	4000 pounds in inch-pounds	6000 pounds in inch-pounds	8000 pounds in inch-pounds	10 000 pounds in inch-pounds	12 000 pounds in inch-pounds	14 000 pounds in inch-pounds	16 000 pounds in inch-pounds	18 000 pounds in inch-pounds	20 000 pounds in inch-pounds
1	45	177	398	708	1105	1590	2170	2830	3580	....
2	37	148	333	593	927	1332	....	....	....	....
3	15	61	137	244	381	549	746	976	1232	1523
4	52	208	469	....	....	....	....	....	....	....
5	44	177	398	708	1109	....	....	....	....	....
6	20	79	177	316	494	710	966	....	....	....
7	38	152	343	610	954	1371	....	....	....	....
8	15	61	137	243	380	548	746	973	1232	1521
9	55	220	494	879	....	....	....	....	....	....
10	20	86	180	320	500	720	980	1280	1530	1900
11	35	138	310	551	860	1235	....	....	....	....
12	27	107	241	428	668	963	1310	1710	....	....
13	11	45	105	179	279	402	547	714	903	1116
14	31	126	282	502	785	....	....	....	....	....
15	19	75	168	299	468	672	914	1195	1512	1866
16	47	186	418	744	1160	1675	2280	....	....	....
17	19	77	173	308	481	693	943	1232	1558	1924
18	21	86	193	343	536	772	1050	1374	1740	2146
19	30	119	269	477	745	1073	1460	1906	2413	2975
20	44	176	396	705	1100	1584	....	....	....	....
21	70	270	555	900	1300	1740	2240	2760	3380	4000

The character of the failure due to side thrust will be found on the summary sheet for each wheel.

In the majority of tests failure occurred in the spokes, near the hub. This was to be expected because of the large bending moment at that section.

As indicated by the load-deflection curves, large stresses are transmitted through the rim to the portion of the wheel diametrically opposite to that on which the load is applied.

To obtain the actual deformation of the wheel it would be necessary to make a correction due to the bending of the axle. Comparative results only were required and, except in a few tests, no attempt was made to measure the bending of the axle.

In these tests the deflection of the axle was measured at a point which was at the same distance from the support as the deflection points on the edge of the rim. In this way, for a given load the actual deformation of the wheel, either at the point where the load is applied or at the diametrically opposite point, is obtained by subtracting the deflection of the axle from the total deflection of the wheel.

Each load-deflection curve of the axle is shown plotted with the other curves of the test in which the deflection was measured.

As previously stated, the proportional limit is the point at which the rate of deformation changes, and beyond which the wheel becomes permanently deformed. The slope of the load-deformation curve is a measure of the stiffness of the wheel for loads below the proportional limit.

The initial deviation of the load-deformation curve from a straight line is more pronounced here than in the radial-compression tests and again is probably due to localization of strains and to bringing the axle and bushings to a firm bearing.

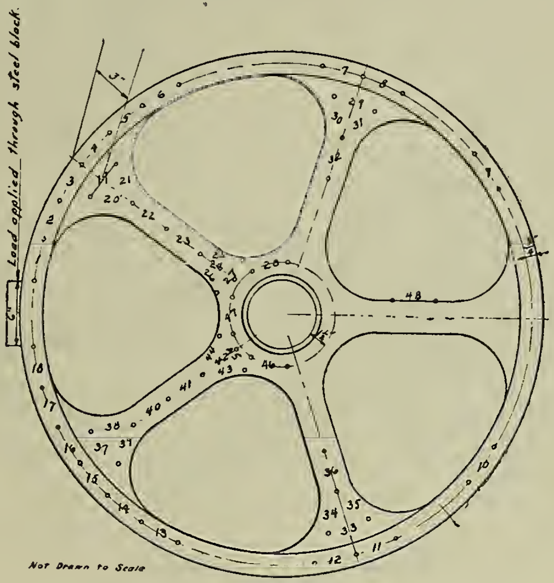


Fig. 4.—*Location of strain gage points, cast-steel, hollow-spoke wheel*

VII. DISTRIBUTION OF STRESS IN WHEEL

An attempt was made to determine the distribution of stress in a wheel under radial-compressive loads. Wheel No. 11, the cast-steel wheel having five hollow spokes, was the only one available at the time, so it was used for the test.

Strain-gage lines were located and numbered as shown on Fig. 4. They were symmetrically placed on either side of a line through the center of the loading block and the center of the wheel. The lines were 2 inches in length, their ends being marked by small holes made with a No. 56 twist drill.

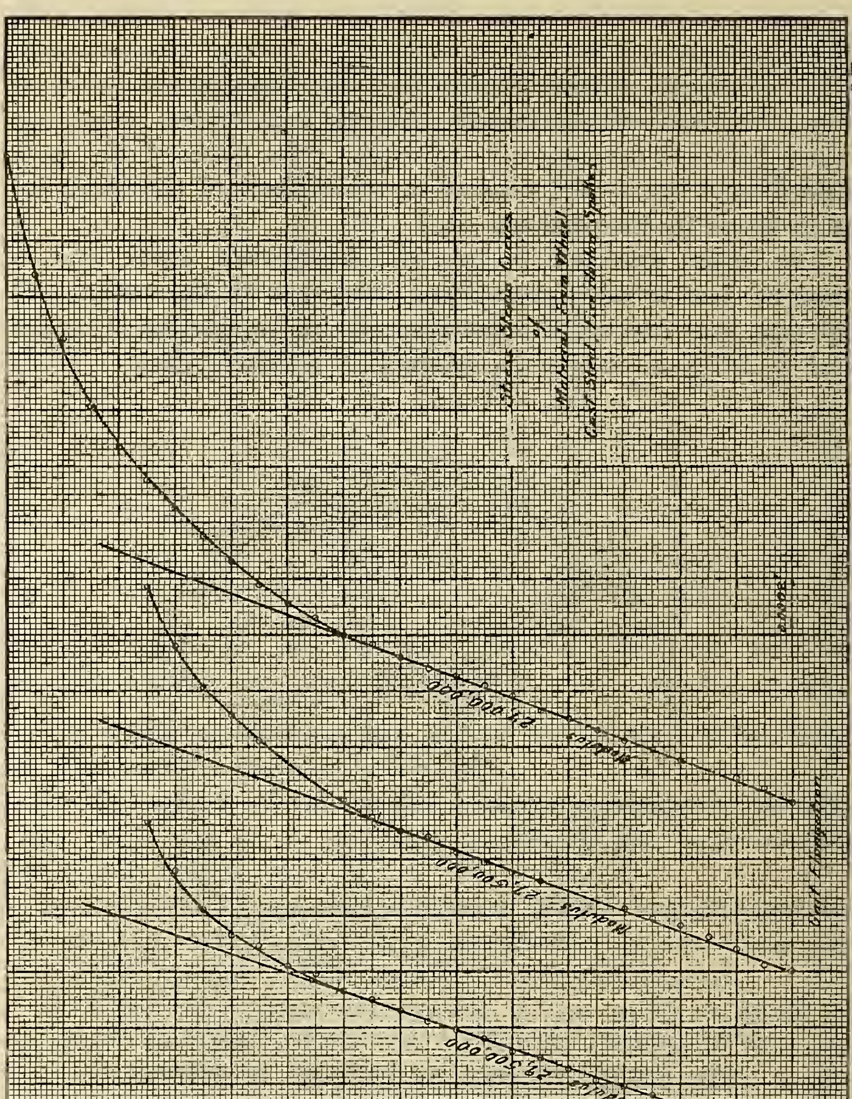


FIG. 5.—*Stress-strain curves of material for cast-steel wheel with five hollow spokes*

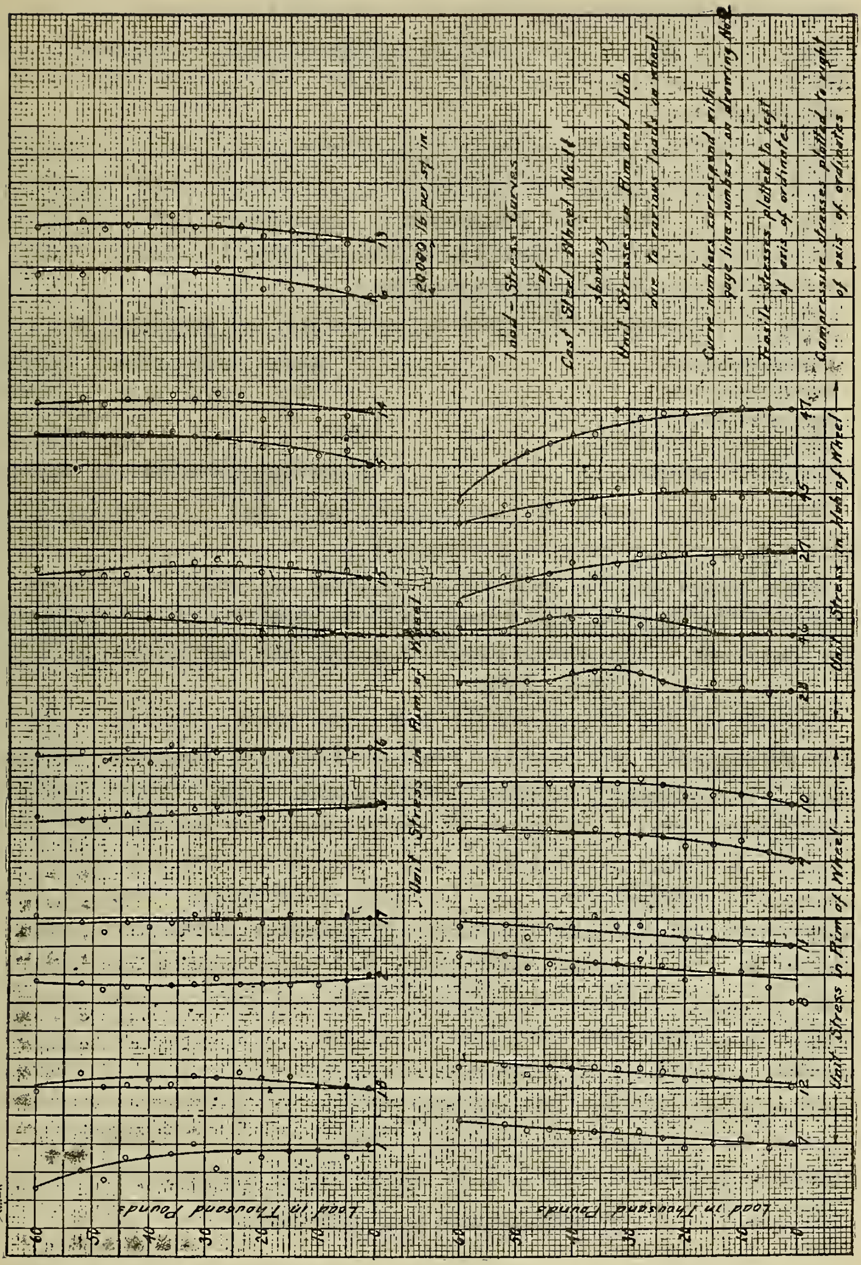


FIG. 6.—Load-stress curves, wheel No. 11, showing stresses in rim and hub

The wheel was subjected to a radial-compressive test as described in Section V. At each load increment the change in length of each strain-gage line was measured by means of a 2-inch Berry strain gage. The smallest change in length indicated by the gage dial was 0.0002 inch. Changes of 0.00002 inch could be estimated.

The reduction of these linear measurements to stresses necessitated the determination of the modulus of elasticity of the material of which the wheel was constructed. Specimens were therefore cut from the spokes of the wheel and subjected to tensile tests. The results are shown plotted on Fig. 5.

The average mechanical properties determined are listed below:

Ultimate strength	pounds per square inch	61 000
Proportional limit	do	17 700
Reduction in area	per cent	17.3
Elongation in 2 inches	do	12.0
Modulus of elasticity	pounds per square inch	28 000 000

This average value of the modulus was used in reducing the strain-gage measurements to stresses.

Load-stress curves were then plotted to show the relation between the load on the wheel and the unit stresses introduced by that load. The curves for the rim and hub are shown on Fig. 6, those for the spokes on Fig. 7.

Curves for gage lines similarly located, with reference to the line through the center of the loading block and the center of the wheel, were plotted in pairs. These curves check fairly closely. Exact duplication was not to be expected as the curves show the relation between applied load and unit stress, and not that between the applied load and the load transmitted through the section, so that, while the loads transmitted through symmetrically located sections are equal, any difference in the thickness or other dimensions of the casting at these points would result in a difference in the unit stresses. For example, spoke sections 22 and 40 will each transmit equal parts of any external load applied through the loading block. If, however, the cross section of the spoke at 22 is less than that of the spoke at 40, then the unit stress at 22 will be greater than the unit stress at 40

1. STRESSES IN RIM OF WHEEL

It is evident from the load-stress curves for the rim that the circumferential stresses do not exceed the proportional limit of the material (17 700 pounds per square inch) for any load on the wheel up to 60 000 pounds.

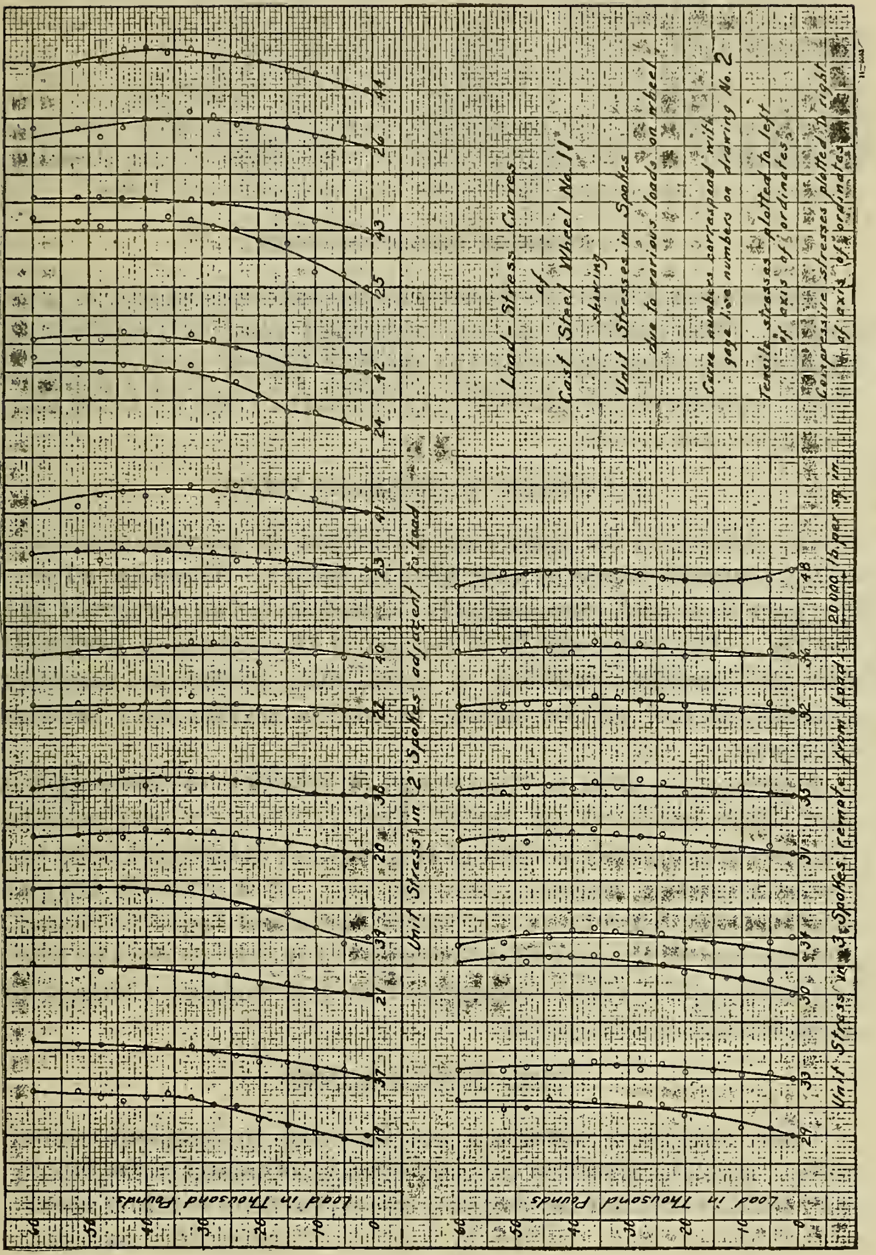


FIG. 7.—Load-stress curves, wheel No. 11, showing stresses in spokes

These stresses are compressive in all parts of the rim except in the section between the spokes adjacent to the loading block. These spokes are inclined in the direction of the applied load, and the circumferential components of their reactions to the load are such as to produce tensile stresses in the rim between the spokes. Stresses due to beam action in the section have no appreciable effect on the measurements as the gage lines were approximately on the neutral axis of the beam. The shearing stresses were not measured but are undoubtedly very large.

2. STRESSES IN HUB OF WHEEL

The stresses in the hub do not become excessive except at gage line 47. The tensile stresses at this point pass the proportional limit of the material when the applied load is 50 000 pounds. There is, however, no possibility of a wheel in service being subjected to such a load.

3. STRESSES IN SPOKES OF WHEEL

The stresses in the spokes are all within the porportional limit of the material except at gage lines 24 and 25. These are adjoining gage lines and were probably located in a thin section of the casting. Any reduction from section of the casting as designed, due to blowholes, shifting of cores, etc., should be carefully guarded against as the strains in such a section may become excessive.

Attention is called to the change in direction of many of the load-stress curves at an applied load of about 32 000 pounds. This is the proportional limit of the wheel as determined from the load-deformation curves. (See Fig. 18.) It is probable that at this load the distribution of stress in the wheel began to change. The increase in the rate of deformation of the rim under the loading block would cause a readjustment and perhaps a change in kind of stress in the spokes.

VIII. CONCLUSIONS

These laboratory tests are not intended to supplant service tests. Much information can, however, be obtained in the laboratory which could not be obtained by service tests within a reasonable length of time. Defects in design and material are soon made apparent in laboratory tests and changes can be made before wheels are manufactured in large quantities.

The wheels tested were representative of those used on 3 and 5 ton trucks, and it is quite improbable that any of these wheels would ever be stressed even to its proportional limit.

The wheels tested are all stronger and heavier than is necessary, and a saving in material should be effected.

A reduction in weight is worthy of consideration, not only because of the material saved, but also because it would result in an increase in the life of tires and of roads.

IX. SUMMARY SHEETS AND CURVES

In the following pages are recorded the results of the tests.

Each summary sheet contains all of the information obtained from the tests on a single wheel. On the page facing the summary sheet are the load-deformation curves for that wheel.

TABLE 8.—Wheel No. 1

[Description—Rear wheel, 36 by 10 inches; wood, 14 spokes. Weight—252 pounds]

RADIAL-COMPRESSION TESTS

Proportional limit in pounds	38 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.1062
Permanent set at maximum load in inches	0.0336
Slope of curve No. 2 in pounds per inch	826 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	875
270° from load	352
180° from load	280
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	3.47
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	10
6000 pounds	22
8000 pounds	39
10 000 pounds	61
12 000 pounds	87
14 000 pounds	118
16 000 pounds	155
18 000 pounds	196
20 000 pounds	242

SIDE-THRUST TEST

Proportional limit in pounds	18 000
Ultimate strength in pounds	43 700
Slope of curve in pounds per inch	45 200
Elastic resiliency in inch-pounds:	
At load	3185
180° from load	1800
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	12.65
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	45
4000 pounds	117
6000 pounds	398
8000 pounds	708
10 000 pounds	1105
12 000 pounds	1590
14 000 pounds	2170
16 000 pounds	2830
18 000 pounds	3580

Character of failure: Failed by splitting of spokes near point of application of load and at 180° from that point. Six spokes split near point of application of load. Four spokes split at 180° from point of application of load. Felly moved one-half inch along spokes at point of application of load.

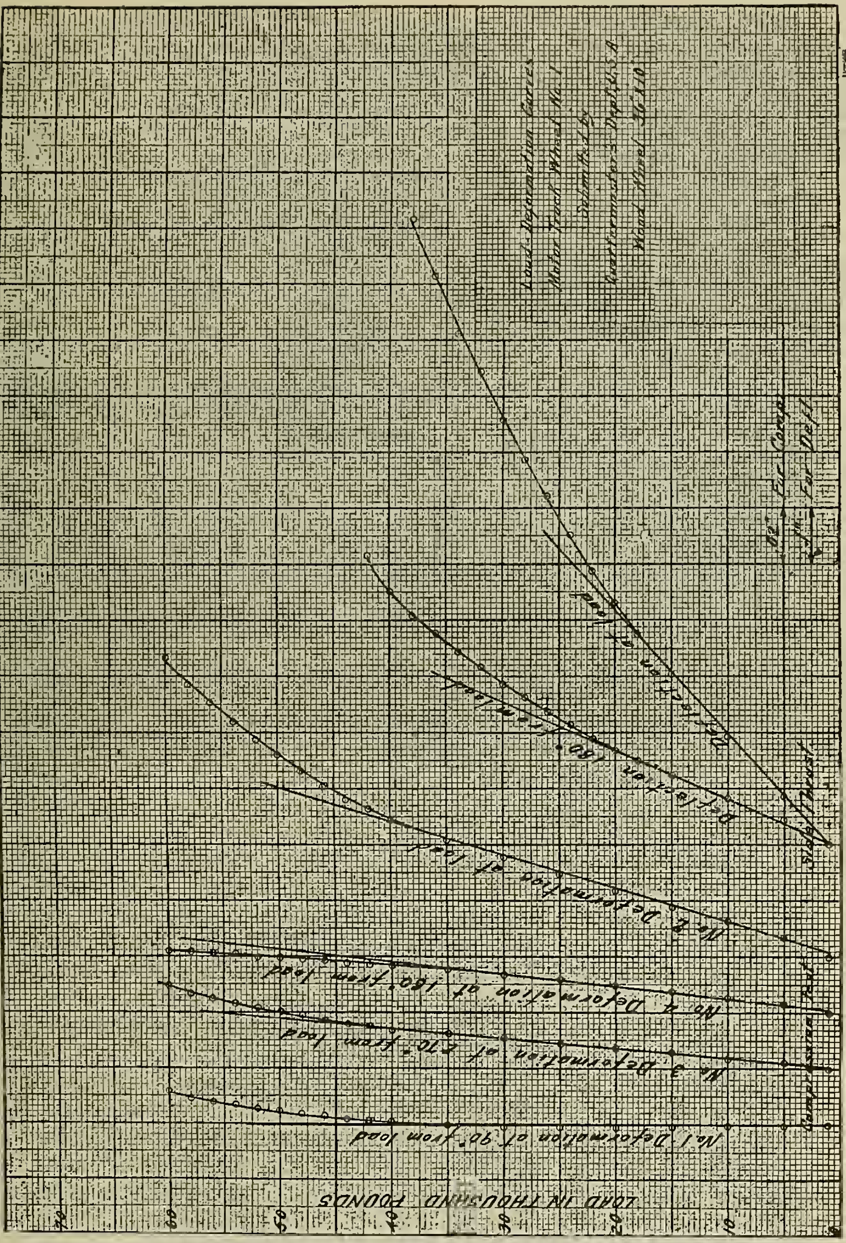


Fig. 8.—Load-deformation curves, wheel No. 1

TABLE No. 9.—Wheel No. 2

[Description—Front wheel, 36 by 5 inches; cast-steel disk, box rim. Weight—169 pounds. Chemical analysis (per cent)—Carbon, 0.34; sulphur, 0.048; phosphorus, 0.039; manganese, 0.61; silicon, 0.35]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	31 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.0359
Permanent set at maximum load in inches	0.0187
Slope of curve No. 2 in pounds per inch	2 450 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	202
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	1.20
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	3
6000 pounds	7
8000 pounds	13
10 000 pounds	20
12 000 pounds	29
14 000 pounds	40
16 000 pounds	52
18 000 pounds	66
20 000 pounds	82

SIDE-THURST TEST	
Proportional limit in pounds	12 000
Ultimate strength in pounds	48 100
Slope of curve in pounds per inch	54 000
Elastic resiliency in inch-pounds:	
At load	1333
180° from load	980
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	7.90
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	37
4000 pounds	148
6000 pounds	333
8000 pounds	593
10 000 pounds	927
12 000 pounds	1332

Character of failure: Failed by bending of entire wheel. No signs of rupture in material except small cracks in felly.

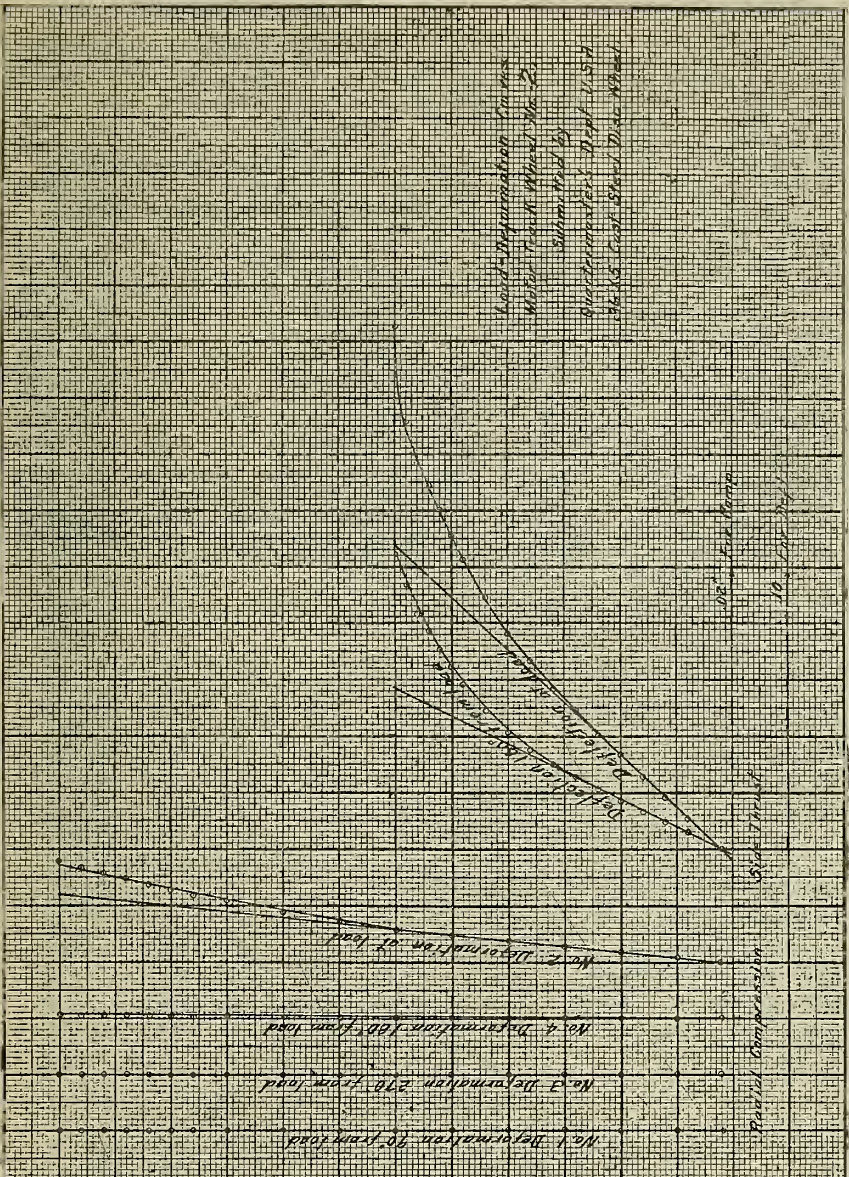


FIG. 9.—*Load-deformation curves, wheel No. 2*

TABLE 10.—Wheel No. 3

[Description—Rear wheel, 36 by 10 inches; cast-steel disk; box rim. Weight—268 pounds. Chemical analysis (per cent)—Carbon, 0.33; sulphur, 0.051; phosphorus, 0.046; manganese, 0.74; silicon, 0.36]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	50 000
Maximum applied load in pounds	100 000
Deformation at maximum load in inches	0.0881
Permanent set at maximum load in inches	0.0261
Slope of curve No. 2 in pounds per inch	1 891 000
Elastic resiliencies in inch-pounds:	
90° from load	128
At load	660
270° from load	447
180° from load	715
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	2.46
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	10
8000 pounds	17
10 000 pounds	26
12 000 pounds	38
14 000 pounds	52
16 000 pounds	68
18 000 pounds	86
20 000 pounds	106

SIDE-THRUST TEST

Proportional limit in pounds	36 500
Ultimate strength in pounds	75 500
Slope of curve in pounds per inch	131 300
Elastic resiliency in inch-pounds:	
At load	5060
180° from load	2640
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	18.90
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	15
4000 pounds	61
6000 pounds	137
8000 pounds	244
10 000 pounds	381
12 000 pounds	549
14 000 pounds	746
16 000 pounds	976
18 000 pounds	1232
20 000 pounds	1523

Character of failure: Failed by bending of entire wheel. Below point of application of load a crack 6 inches long ran from circumference of wheel toward the hub. Tension hair cracks developed along arc of 180° at bottom of slope from hub.

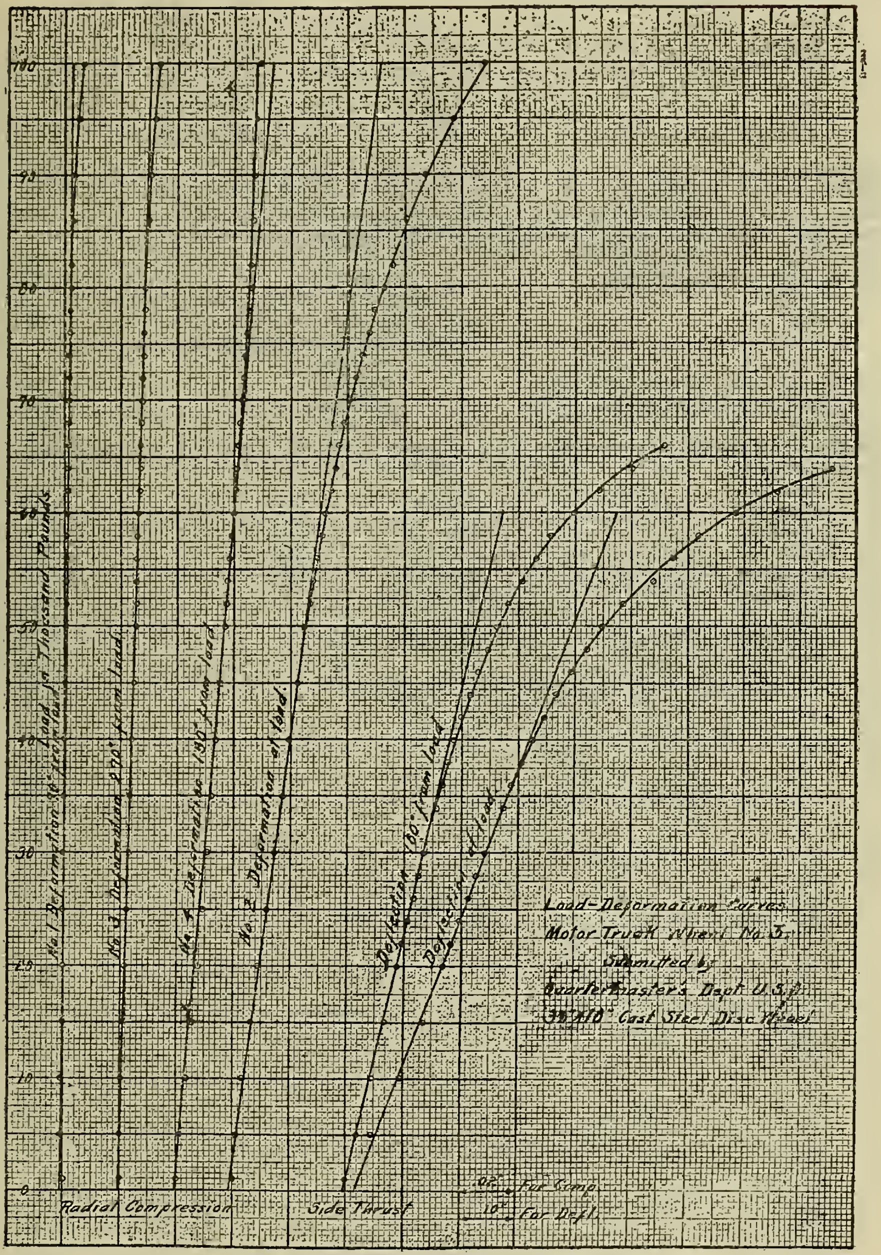


FIG. 10.—*Load-deformation curves, wheel No. 3*

TABLE 11.—Wheel No. 4

[Description—Front wheel, 40 by 6 inches; pressed steel, corrugated web; channel iron rim. Weight—181 pounds. Chemical analysis (per cent.)

	Hub	Web	Rim
Carbon	0.19	0.15	0.11
Sulphur	0.046	0.063	0.050
Phosphorus	0.030	0.044	0.092
Manganese	0.59	0.48	0.40
Silicon	0.28	0.02	0.02]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	34 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.0564
Permanent set at maximum load in inches	0.0072
Slope of curve No. 2 in pounds per inch	1 238 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	467
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	2.58
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	7
6000 pounds	15
8000 pounds	26
10 000 pounds	40
12 000 pounds	58
14 000 pounds	79
16 000 pounds	103
18 000 pounds	131
20 000 pounds	162

SIDE-THRUST TEST

Proportional limit in pounds	6000
Ultimate strength in pounds	19 000
Slope of curve in pounds per inch	385 000
Elastic resiliency in inch-pounds:	
At load	468
180° from load	575
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	2.58
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	52
4000 pounds	208
6000 pounds	469

Character of failure: Failed by web pulling from hub.

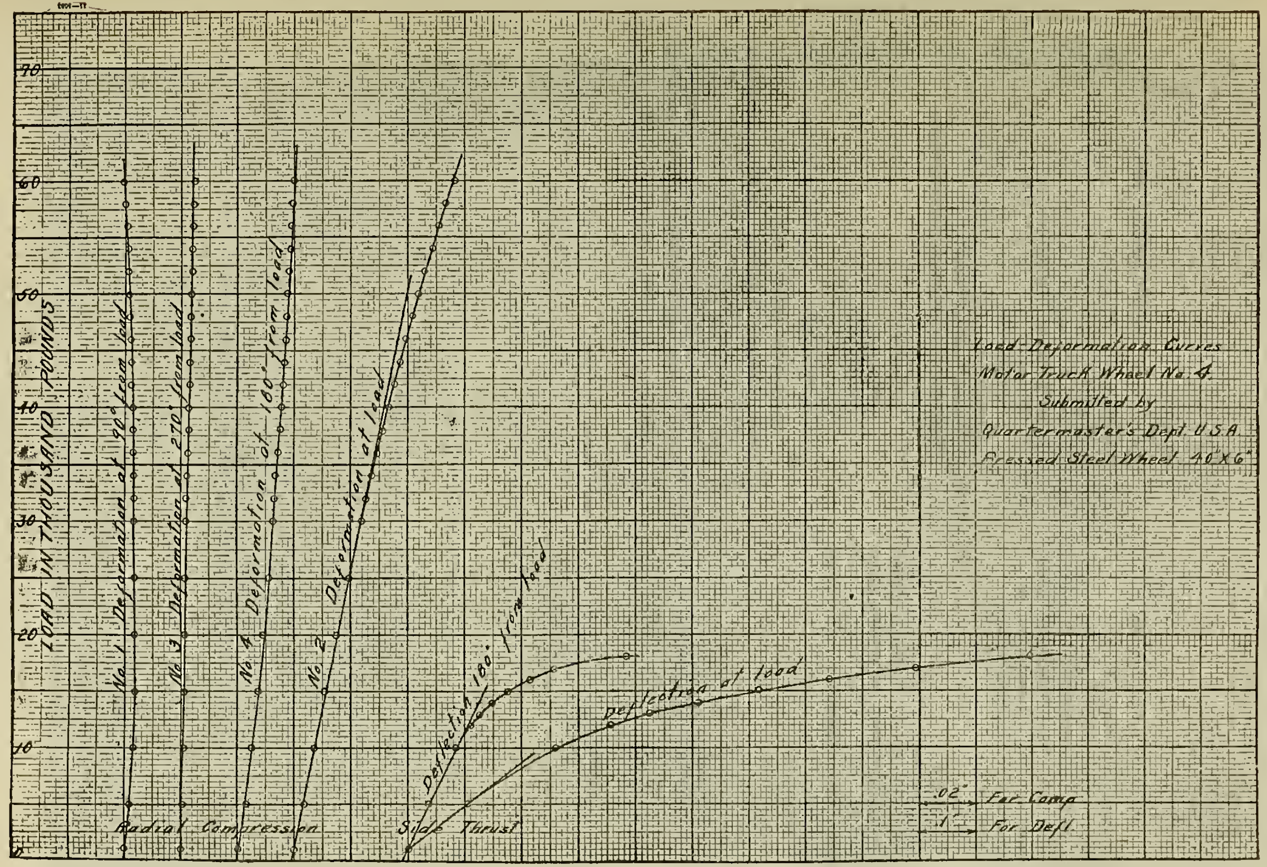


FIG. 11.—Load-deformation curves, wheel No. 4

TABLE 12.—Wheel No. 5

[Description—Rear wheel, 40 by 12 inches; pressed steel, corrugated web; channel iron rim. Weight—354 pounds. Chemical analysis (per cent)

	Hub	Web	Rim
Carbon	0.19	0.15	0.11
Sulphur	0.046	0.063	0.050
Phosphorus	0.030	0.044	0.092
Manganese	0.59	0.48	0.40
Silicon	0.28	0.02	0.02]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	85 000
Maximum applied load in pounds	[a] 105 000
Deformation at maximum load in inches	0.1631
Permanent set at maximum load in inches	0.0428
Slope of curve No. 2 in pounds per inch	715 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	5050
270° from load	
180° from load	725
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	14.3
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	4
4000 pounds	12
6000 pounds	30
8000 pounds	54
10 000 pounds	80
12 000 pounds	108
14 000 pounds	147
16 000 pounds	208
18 000 pounds	261
20 000 pounds	330

SIDE-THRUST TEST	
Proportional limit in pounds	10 000
Ultimate strength in pounds	25 000
Slope of curve in pounds per inch	45 200
Elastic resiliency in inch-pounds:	
At load	1108
180° from load	618
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	3.15
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	44
4000 pounds	177
6000 pounds	398
8000 pounds	708
10 000 pounds	1109

Character of failure: Failed by web pulling from hub. Failure was more pronounced at 90° from the load than it was at the point where the load was applied. This was probably due to the crack in the rim of the wheel (caused by parting of channel irons) which had developed during the radial compression test. The brake band pulled away from the web.

---

[a] Crack developed along rim of wheel where the two channels, of which the rim is formed, were welded.

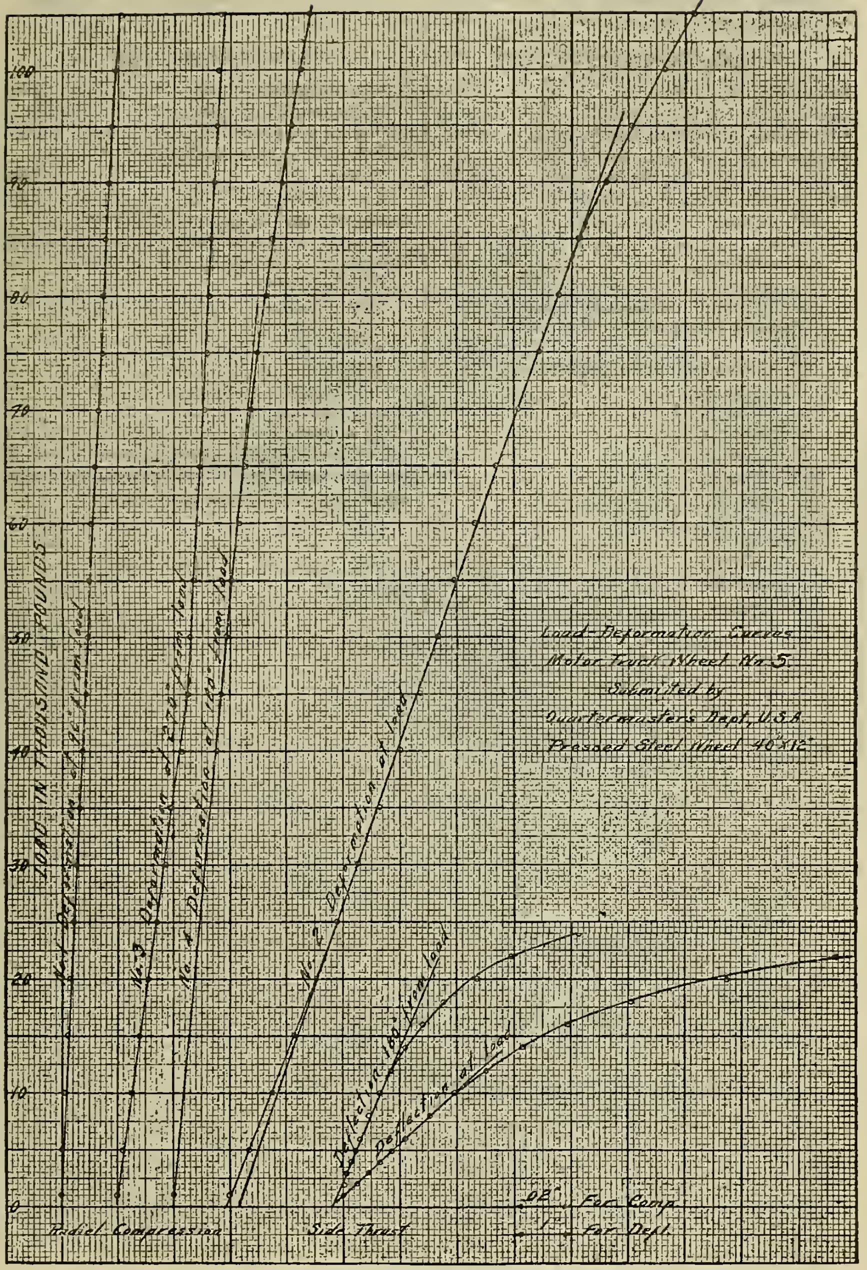


FIG. 12.—*Load-deformation curves, wheel No. 5*

TABLE 13.—Wheel No. 6

[Description—Rear wheel, 36 by 6 inches; cast steel; 8+ spokes; brake band cast on wheel. Weight—215 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.083; phosphorus, 0.054; manganese, 0.64; silicon, 0.35]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	31 000
Maximum applied load in pounds	75 000
Deformation at maximum load in inches	0.0847
Permanent set at maximum load in inches	0.0291
Slope of curve No. 2 in pounds per inch	1 875 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	257
270° from load	
180° from load	
Elastic resiliency in inch-pounds at point of application of load, per pound of metal in wheel	1.20
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	10
8000 pounds	17
10 000 pounds	27
12 000 pounds	38
14 000 pounds	52
16 000 pounds	68
18 000 pounds	86
20 000 pounds	107

SIDE-THRUST TEST	
Proportional limit in pounds	15 500
Ultimate strength in pounds	54 000
Slope of curve in pounds per inch	101 300
Elastic resiliency in inch-pounds:	
At load	1185
180° from load	1470
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	5.51
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	20
4000 pounds	79
6000 pounds	177
8000 pounds	316
10 000 pounds	494
12 000 pounds	710
14 000 pounds	966

Character of failure: Tension failure at root of four spokes near point of application of load. Also tension failure in rim near same point.

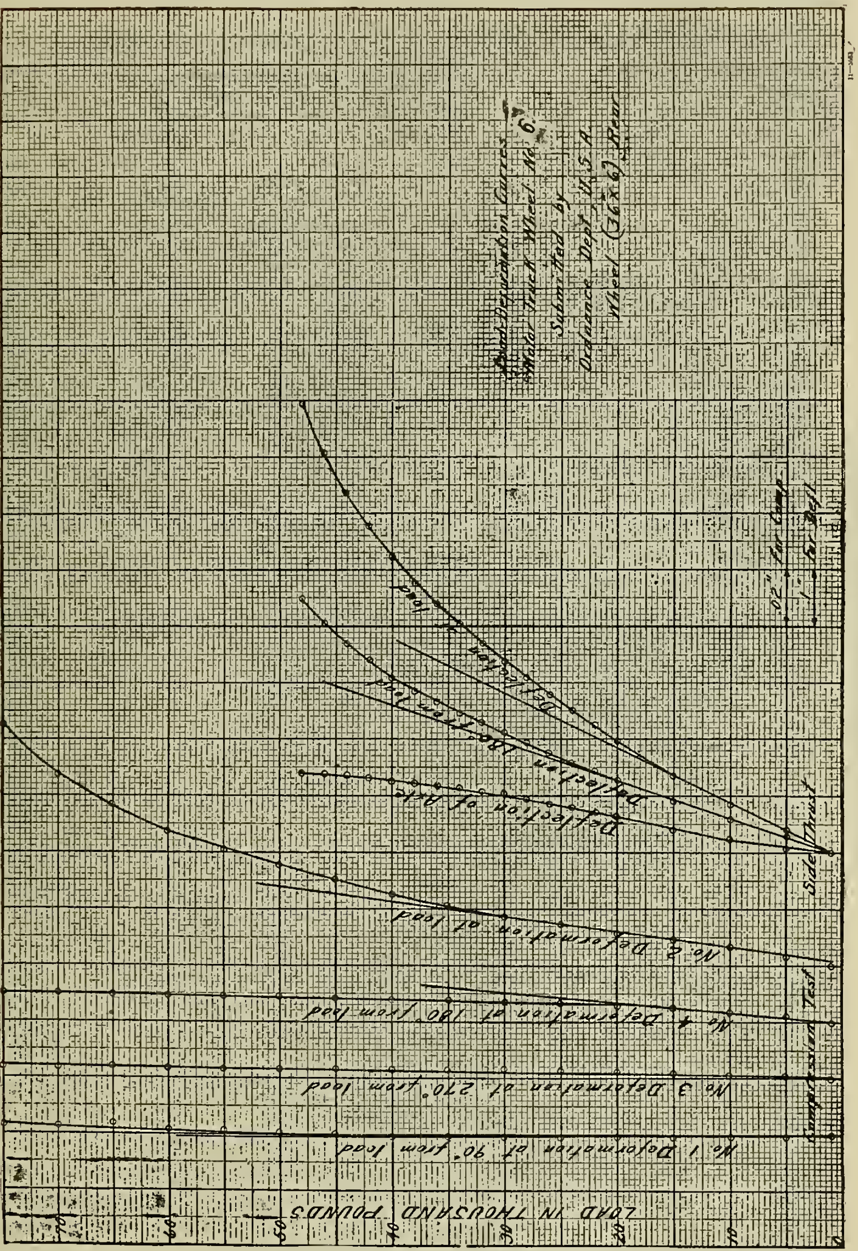


FIG. 13.—*Load-deformation curves, wheel No. 6*

TABLE 14.—Wheel No. 7

[Description—Front wheel, 36 by 5 inches; cast steel; 8 U spokes; box rim. Weight—134 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.081; phosphorus, 0.060; manganese, 0.74; silicon, 0.29]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	32 500
Maximum applied load in pounds	50 000
Deformation at maximum load in inches	0.0490
Permanent set at maximum load in inches	0.0135
Slope of curve No. 2 in pounds per inch	1 363 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	387
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	2.89
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	6
6000 pounds	13
8000 pounds	24
10 000 pounds	37
12 000 pounds	53
14 000 pounds	72
16 000 pounds	94
18 000 pounds	119
20 000 pounds	147

SIDE-THRUST TEST

Proportional limit in pounds	13 000
Ultimate strength in pounds	31 100
Slope of curve at load in pounds per inch	52 500
Elastic resiliency in inch-pounds:	
At load	1610
180° from load	595
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	12.00
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	38
4000 pounds	152
6000 pounds	343
8000 pounds	610
10 000 pounds	954
12 000 pounds	1371

Character of failure: Tension failure in spoke near point of application of load, and in webbing between spokes at 180° from load.

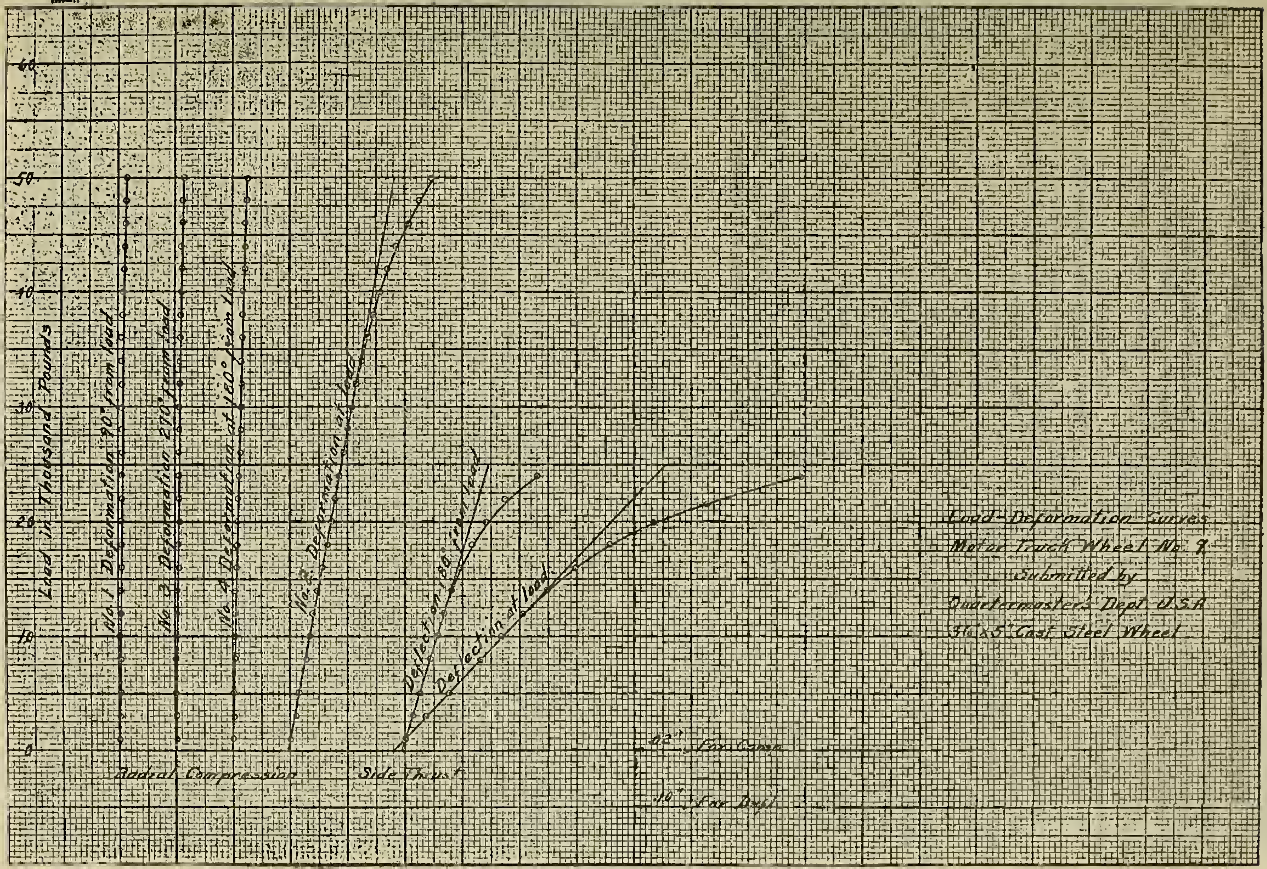


FIG. 14.—Load-deformation curves, wheel No. 7

TABLE 15.—Wheel No. 8

[Description—Rear wheel, 36 by 10 inches; cast steel; 8 U spokes; box rim. Weight—274 pounds. Chemical analysis (per cent)—Carbon, 0.14; sulphur, 0.081; phosphorus, 0.080; manganese, 0.78; silicon, —]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	50 000
Maximum applied load in pounds	100 000
Deformation at maximum load in inches	0.0610
Permanent set at maximum load in inches	0.0103
Slope of curve No. 2 in pounds per inch	2 000 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	625
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	2.28
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	9
8000 pounds	16
10 000 pounds	25
12 000 pounds	36
14 000 pounds	49
16 000 pounds	64
18 000 pounds	81
20 000 pounds	100

SIDE-THRUST TEST	
Proportional limit in pounds	34 500
Ultimate strength in pounds	65 000
Slope of curve at load in pounds per inch	131 500
Elastic resiliency in inch-pounds:	
At load	4520
180° from load	2880
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	16.50
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	15
4000 pounds	61
6000 pounds	137
8000 pounds	243
10 000 pounds	380
12 000 pounds	548
14 000 pounds	746
16 000 pounds	973
18 000 pounds	1232
20 000 pounds	1521

Character of failure: Tension failure at root of spokes near point of application load and in webbing and web bracing 180° from load.

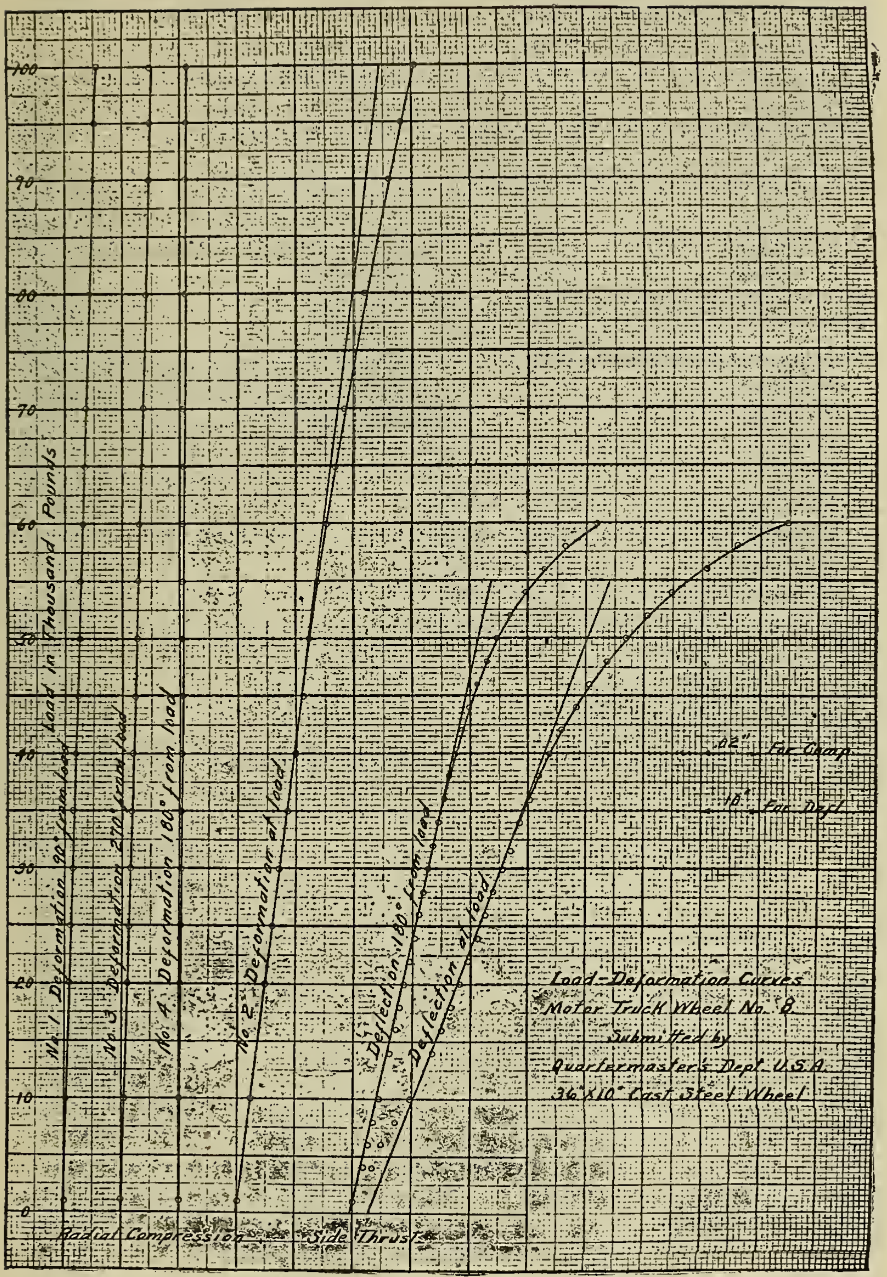


FIG. 15 —*Load-deformation curves, wheel No. 8*

TABLE 16.—Wheel No. 9

[Description—Front wheel, 36 by 5 inches; cast steel; 7 U spokes; box rim. Weight—136 pounds. Chemical analysis (per cent)—Carbon, 0.22; sulphur, 0.057; phosphorus, 0.038; manganese, 0.52; silicon, 0.266]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	35 500
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.1287
Permanent set at maximum load in inches	0.0791
Slope of curve No. 2 in pounds per inch	667 000
Elastic resiliencies in inch-pounds:	
90° from load	119
At load	1047
270° from load	150
180° from load	
Elastic resiliencies in inch-pounds at point of application of load per pound of metal in wheel	7.70
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	5
4000 pounds	18
6000 pounds	36
8000 pounds	64
10 000 pounds	95
12 000 pounds	138
14 000 pounds	182
16 000 pounds	240
18 000 pounds	297
20 000 pounds	350

SIDE-THRUST TEST	
Proportional limit in pounds	7500
Ultimate strength in pounds	26 700
Slope of curve in pounds per inch	36 400
Elastic resiliency in inch-pounds:	
At load	772
180° from load	413
Elastic resiliency in inch-pounds at load per pound of metal in wheel	5.67
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	55
4000 pounds	220
6000 pounds	494
8000 pounds	879

Character of failure: Tension failure in two spokes at load. One spoke failed near the rim and the other at the hub.

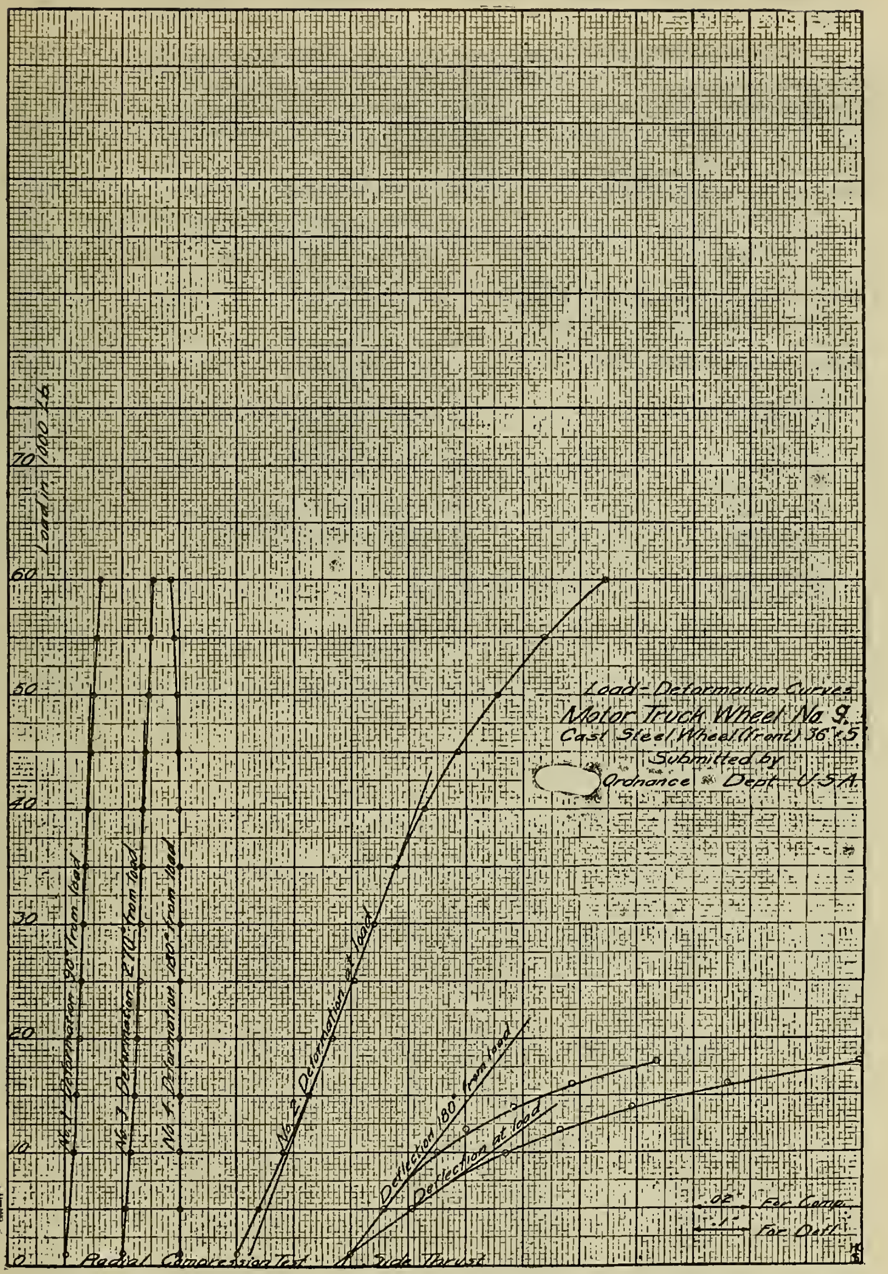


FIG. 16.—*Load-deformation curves, wheel No. 9*

TABLE 17.—Wheel No. 10

[Description—Rear wheel, 36 by 10 inches; cast steel; 7 U spokes; box rim. Weight—321 pounds. Chemical analysis (per cent)—Carbon, 0.23; sulphur, 0.061; phosphorus, 0.041; manganese, 0.62; silicon, 0.305]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	77 000
Maximum applied load in pounds	120 000
Deformation at maximum load in inches	0.1250
Permanent set at maximum load in inches	0.0537
Slope of curve No. 2 in pounds per inch	1 316 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	2250
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load per pound of metal in wheel	7.00
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	5
4000 pounds	17
6000 pounds	39
8000 pounds	64
10 000 pounds	95
12 000 pounds	132
14 000 pounds	168
16 000 pounds	208
18 000 pounds	261
20 000 pounds	310

SIDE-THRUST TEST

Proportional limit in pounds	35 000
Ultimate strength in pounds	81 700
Slope of curve in pounds per inch	125 000
Elastic resiliency in inch-pounds:	
At load	5440
180° from load	4100
Elastic resiliency in inch-pounds at load per pound of metal in wheel	16.9
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	20
4000 pounds	86
6000 pounds	180
8000 pounds	320
10 000 pounds	500
12 000 pounds	720
14 000 pounds	980
16 000 pounds	1280
18 000 pounds	1530
20 000 pounds	1900

Character of failure: Tension failure at root of two spokes adjacent to the load.

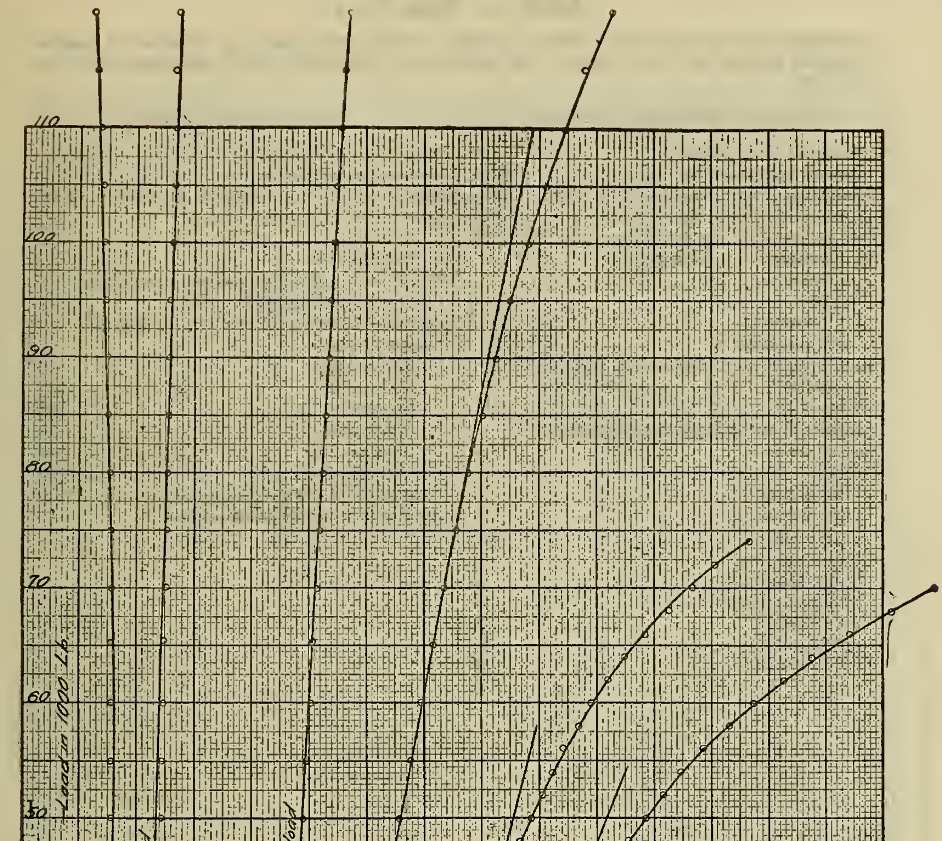


FIG. 17.—*Load-deformation curves, wheel No. 10*

TABLE 18.—Wheel No. 11

Description—Front wheel, 36 by 5 inches; cast steel; 5 hollow spokes; box rim. Weight—144 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.068; phosphorus, 0.040; manganese, 0.85; silicon, 0.23]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	32 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.0695
Permanent set at maximum load in inches	0.0311
Slope of curve No. 2 in pounds per inch	1 160 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	441
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load per pound of metal in wheel	3.06
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	7
6000 pounds	16
8000 pounds	28
10 000 pounds	43
12 000 pounds	62
14 000 pounds	84
16 000 pounds	110
18 000 pounds	140
20 000 pounds	173

SIDE-THRUST TEST

Proportional limit in pounds	13 000
Ultimate strength in pounds	39 300
Slope of curve at load in pounds per inch	58 100
Elastic resiliency in inch-pounds:	
At load	1460
180° from load	1680
Elastic resiliency in inch-pounds at load per pound of metal in wheel	10.10
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	35
4000 pounds	138
6000 pounds	310
8000 pounds	551
10 000 pounds	860
12 000 pounds	1235

Character of failure: Tension failure in hub at 180° from point of application of load.

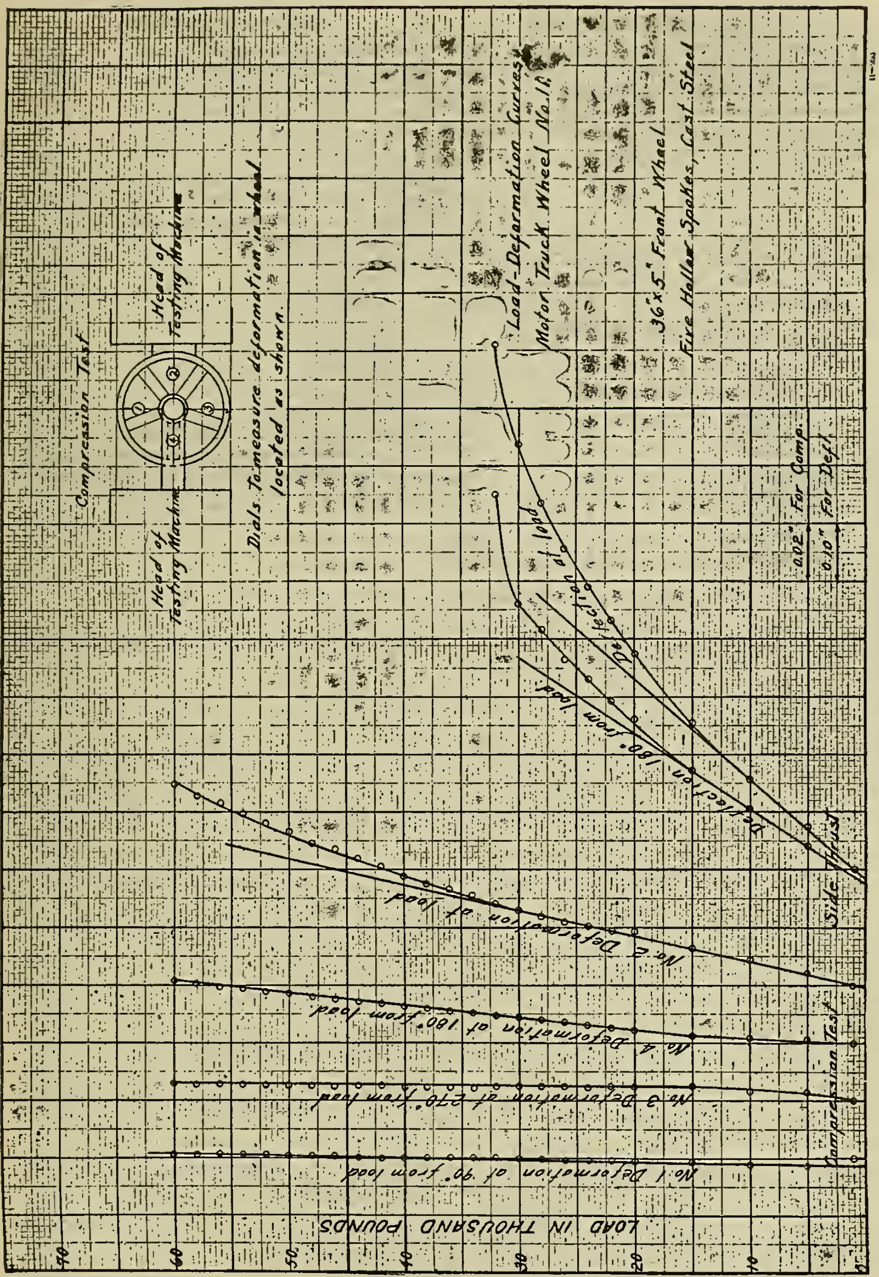


FIG. 18.—Load-deformation curves, wheel No. II

TABLE 19.—Wheel No. 12

[Description—Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; box rim. Weight—130 pounds. Chemical analysis—Carbon, 0.307; sulphur, 0.043; phosphorus, 0.032; manganese, 0.75; silicon, 0.61]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	40 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.0645
Permanent set at maximum load in inches	0.0220
Slope of curve No. 2 in pounds per inch	1 333 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	600
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	4.60
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	6
6000 pounds	14
8000 pounds	24
10 000 pounds	38
12 000 pounds	54
14 000 pounds	74
16 000 pounds	96
18 000 pounds	122
20 000 pounds	150

SIDE-THRUST TEST	
Proportional limit in pounds	16 500
Ultimate strength in pounds	49 200
Slope of curve in pounds per inch	74 800
Elastic resiliency in inch-pounds:	
At load	1820
180° from load	1480
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	14.0
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	27
4000 pounds	107
6000 pounds	241
8000 pounds	428
10 000 pounds	668
12 000 pounds	963
14 000 pounds	1310
16 000 pounds	1710

Character of failure: Failed by buckling on the inside of the wheel near the point of application of load, in the metal at the base of the spokes near the solid metal hub.

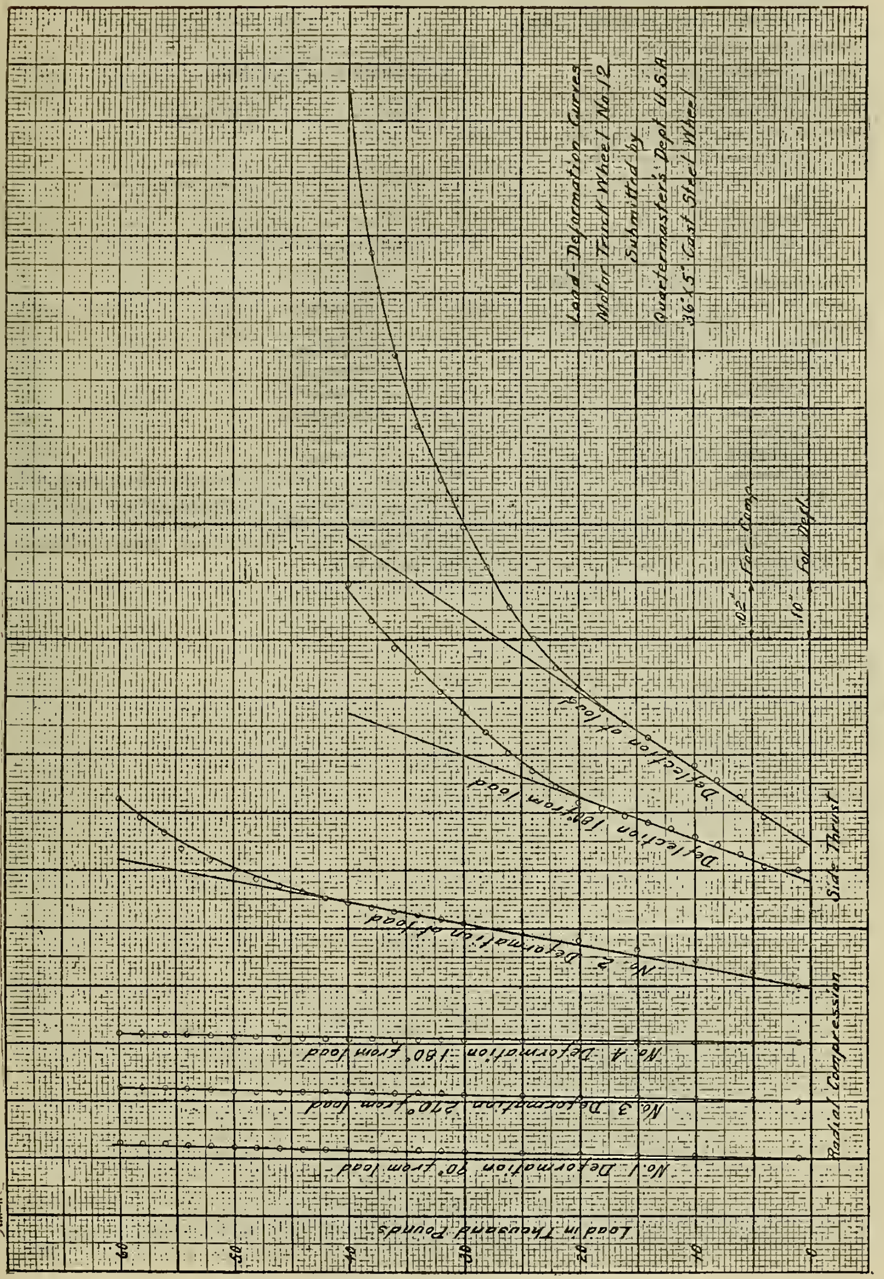


FIG. 19.—*Load-deformation curves, wheel No. 12*

TABLE 20.—Wheel No. 13

[Description—Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; box rim. Weight—286 pounds. Chemical analysis (per cent)—Carbon, 0.362; sulphur, 0.043; phosphorus, 0.038; manganese, 0.76; silicon, 0.54]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	20 000
Maximum applied load in pounds	100 000
Deformation at maximum load in inches	0.0513
Permanent set at maximum load in inches	0.0113
Slope of curve No. 2 in pounds per inch	6 060 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	33
270° from load	
180° from load	390
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	0.10
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	0
4000 pounds	1
6000 pounds	3
8000 pounds	5
10 000 pounds	8
12 000 pounds	12
14 000 pounds	16
16 000 pounds	21
18 000 pounds	27
20 000 pounds	33

SIDE-THRUST TEST	
Proportional limit in pounds	38 000
Ultimate strength in pounds	101 000
Slope of cruve in pounds per inch	179 000
Elastic resiliency in inch-pounds:	
At load	4040
180° from load	5170
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	14.20
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	11
4000 pounds	45
6000 pounds	105
8000 pounds	179
10 000 pounds	279
12 000 pounds	402
14 000 pounds	547
16 000 pounds	714
18 000 pounds	903
20 000 pounds	1116

Character of failure: Apparatus broke at 101 000 pounds, making it necessary to remove the load. On reapplying load, the wheel failed at 98 000 pounds by tension fraction in the steel where the spokes join the hub.

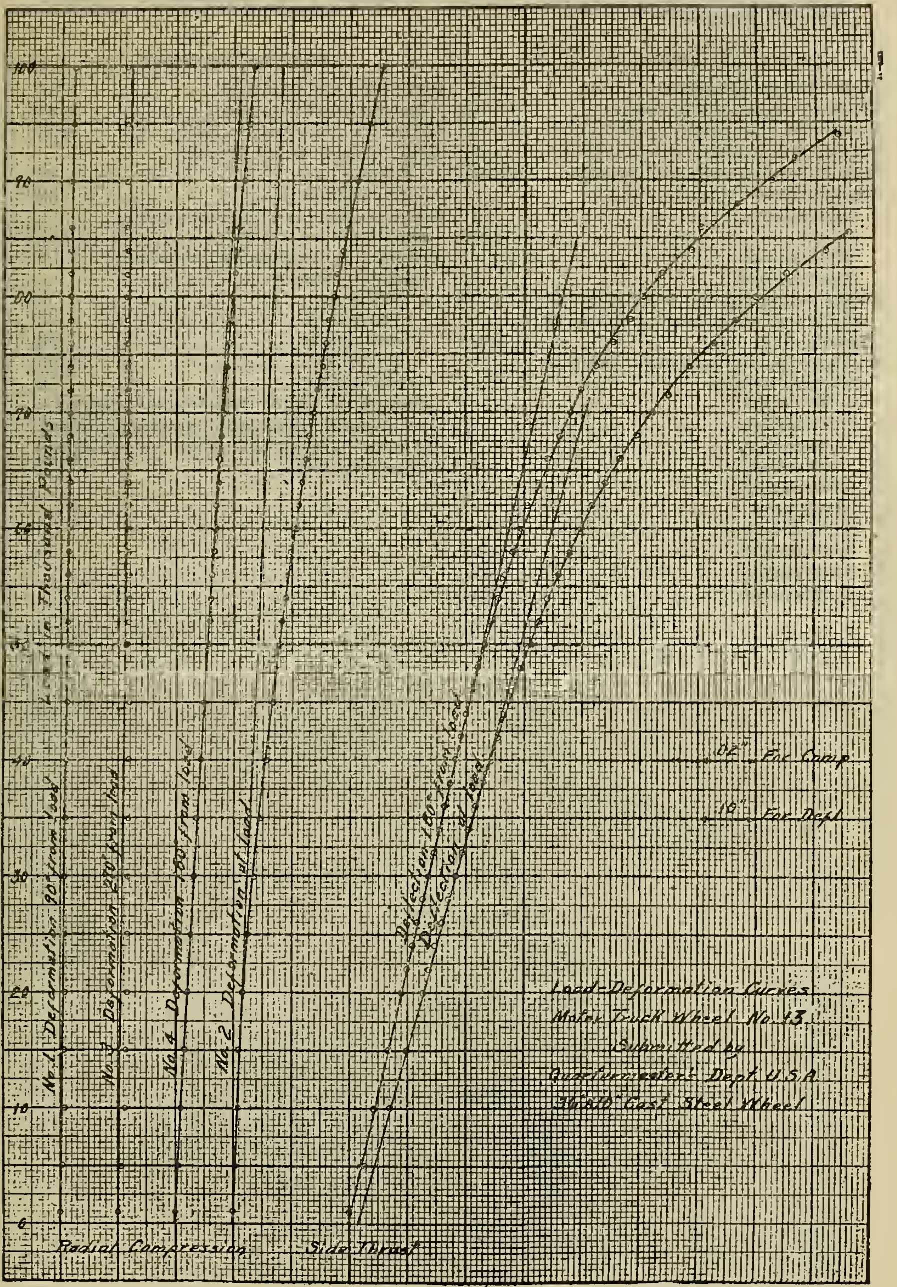


FIG. 20.—*Load-deformation curves, wheel No. 13*

TABLE 21.—Wheel No. 14

[Description—Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design. Weight—132 pounds. Chemical analysis (per cent)—Carbon, 0.30; sulphur, 0.034; phosphorus, 0.021; manganese, 0.47; silicon, 0.40]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	26 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.1135
Permanent set at maximum load in inches	0.0687
Slope of cruve No. 2 in pounds per inch	1 300 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	260
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	1.97
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	6
6000 pounds	14
8000 pounds	25
10 000 pounds	39
12 000 pounds	55
14 000 pounds	75
16 000 pounds	98
18 000 pounds	125
20 000 pounds	154

SIDE-THRUST TEST	
Proportional limit in pounds	10 500
Ultimate strength in pounds	34 000
Slope of cruve in pounds per inch	63 700
Elastic resiliency in inch-pounds:	
At load	865
180° from load	330
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	6.55
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	31
4000 pounds	126
6000 pounds	282
8000 pounds	502
10 000 pounds	785

Character of failure: Failed by the crushing in of one side of tire seat at point of application of load, and by distortion of wheel. There were no signs of rupture in the metal.

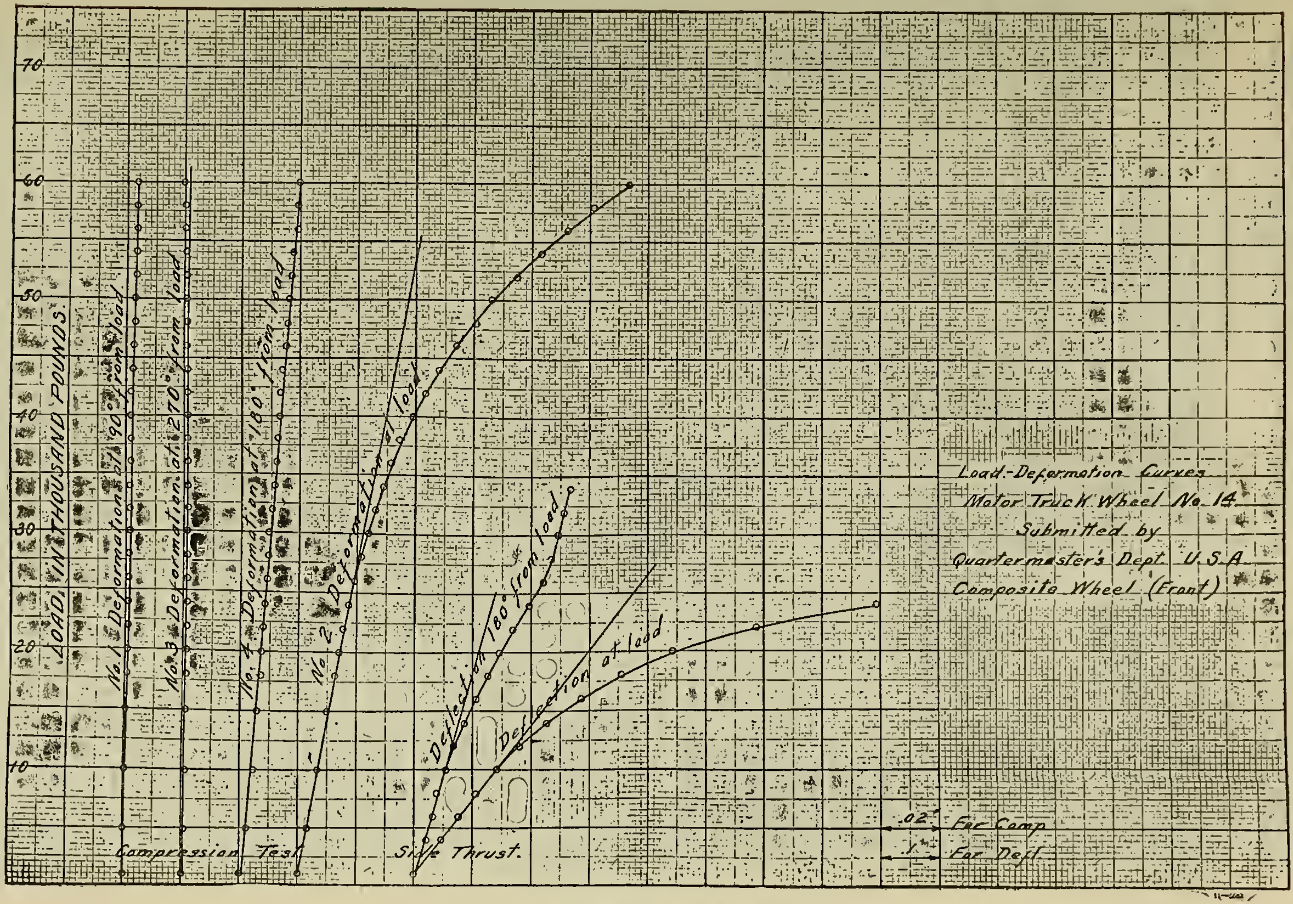


Fig. 21.—Load-deformation curves, wheel No. 14

TABLE 22.—Wheel No. 15

[Description—Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design. Weight—249 pounds. Chemical analysis (per cent)—Carbon, 0.40; sulphur, 0.038; phosphorus, 0.021; manganese, 0.69; silicon, 0.46]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	75 000
Maximum applied load in pounds	120 000
Deformation at maximum load in inches	0.0874
Permanent set at maximum load in inches	0.0318
Slope of curve No. 2 in pounds per inch	2 320 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	1210
270° from load	
180° from load	880
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	4.86
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	8
8000 pounds	14
10 000 pounds	22
12 000 pounds	31
14 000 pounds	42
16 000 pounds	55
18 000 pounds	70
20 000 pounds	86

SIDE-THRUST TEST

Proportional limit in pounds	37 500
Ultimate strength in pounds	68 000
Slope of curve in pounds per inch	107 100
Elastic resiliency in inch-pounds:	
At load	6550
180° from load	6480
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	26.3
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	19
4000 pounds	75
6000 pounds	168
8000 pounds	299
10 000 pounds	468
12 000 pounds	672
14 000 pounds	914
16 000 pounds	1195
18 000 pounds	1512
20 000 pounds	1866

Character of failure: Failed by crushing in of tire seat at point of application of load.

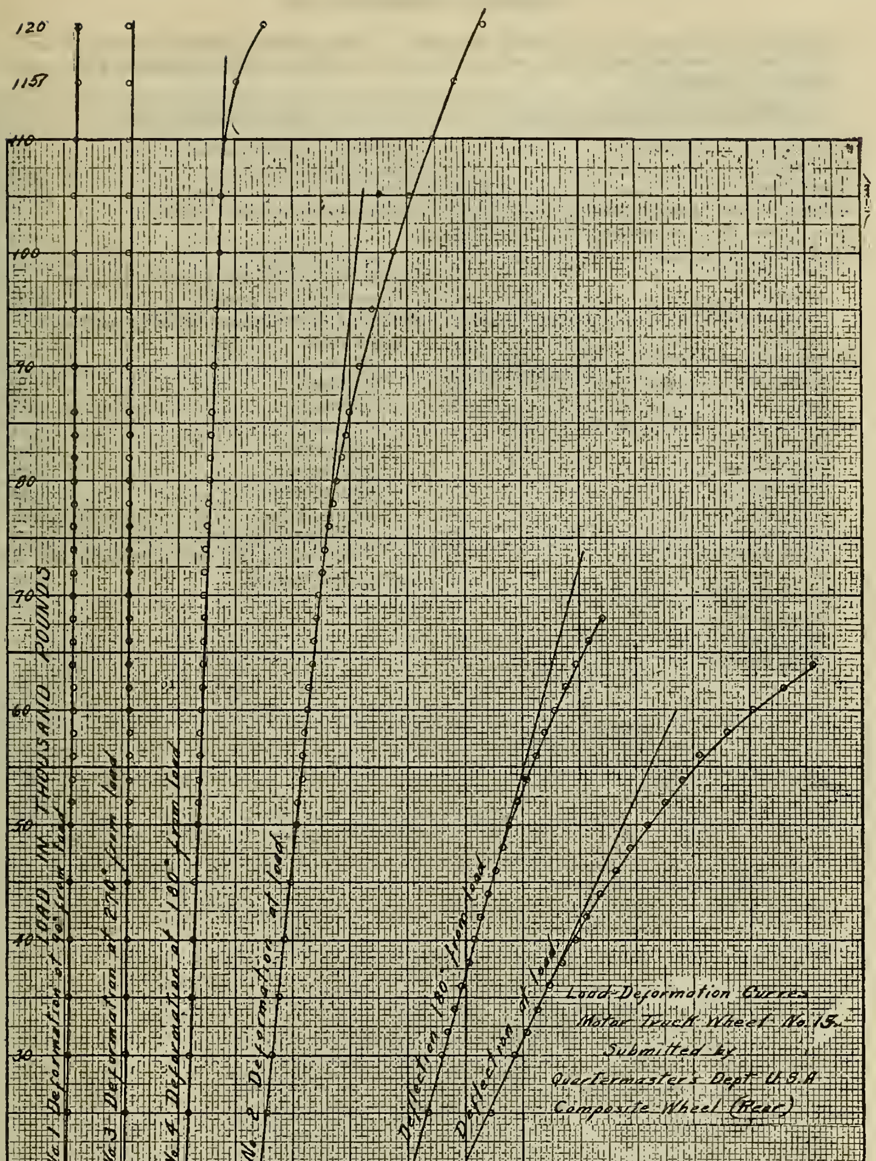


FIG. 22.—*Load-deformation curves, wheel No. 15*

TABLE 23.—Wheel No. 16

[Description—Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design. Weight—120 pounds. Chemical analysis (per cent)—Carbon, 0.211; sulphur, 0.082; phosphorus, 0.066; manganese, 0.84; silicon, 0.40]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	44 000
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.0744
Permanent set at maximum load in inches	0.0323
Slope of curve No. 2 in pounds per inch	917 000
Elastic resiliencies in inch-pounds:	
90° from load	....
At load	1056
270° from load	....
180° from load	....
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	8.80
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	9
6000 pounds	20
8000 pounds	35
10 000 pounds	55
12 000 pounds	79
14 000 pounds	107
16 000 pounds	140
18 000 pounds	177
20 000 pounds	218

SIDE-THRUST TEST

Proportional limit in pounds	14 000
Ultimate strength in pounds	30 200
Slope of curve in pounds per inch	43 000
Elastic resiliency in inch-pounds:	
At load	2280
180° from load	700
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	19.00
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	47
4000 pounds	186
6000 pounds	418
8000 pounds	744
10 000 pounds	1160
12 000 pounds	1675
14 000 pounds	2280

Character of failure: Failed by spokes tearing from hub near point of application of load. This wheel was a poor casting, and cracks developed due to flaws in the material.

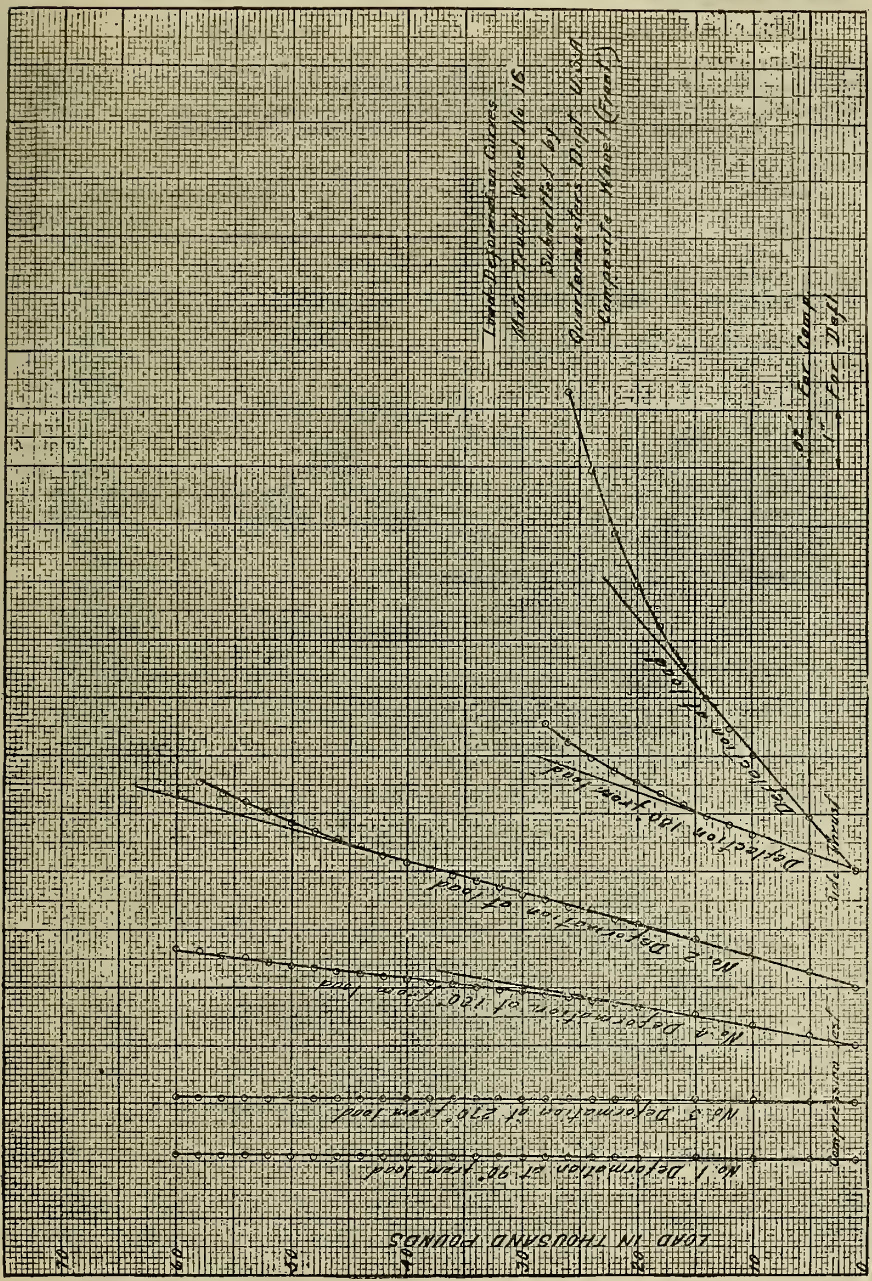


FIG. 23.—*Load-deformation curves, wheel No. 16*

TABLE 24.—Wheel No. 17

Description—Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design. Weight—273 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.084; phosphorus, 0.070; manganese, 0.79; silicon, 0.23]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	71 500
Maximum applied load in pounds	120 000
Deformation at maximum load in inches	0.1586
Permanent set at maximum load in inches	0.0831
Slope of curve No. 2 in pounds per inch	1 250 000
Elastic resiliencies in inch-pounds:	
90° from load	640
At load	2090
270° from load	630
180° from load	319
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	7.65
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	2
4000 pounds	6
6000 pounds	14
8000 pounds	26
10 000 pounds	40
12 000 pounds	58
14 000 pounds	78
16 000 pounds	102
18 000 pounds	130
20 000 pounds	160

SIDE-THRUST TEST

Proportional limit in pounds	40 000
Ultimate strength in pounds	60 600
Slope of curve in pounds per inch	104 000
Elastic resiliency in inch-pounds:	
At load	7 680
180° from load	850
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	28.30
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	19
4000 pounds	77
6000 pounds	173
8000 pounds	308
10 000 pounds	481
12 000 pounds	693
14 000 pounds	943
16 000 pounds	1232
18 000 pounds	1558
20 000 pounds	1924

Character of failure: Failed in hub near root of spokes at point of application of load. Poor casting.

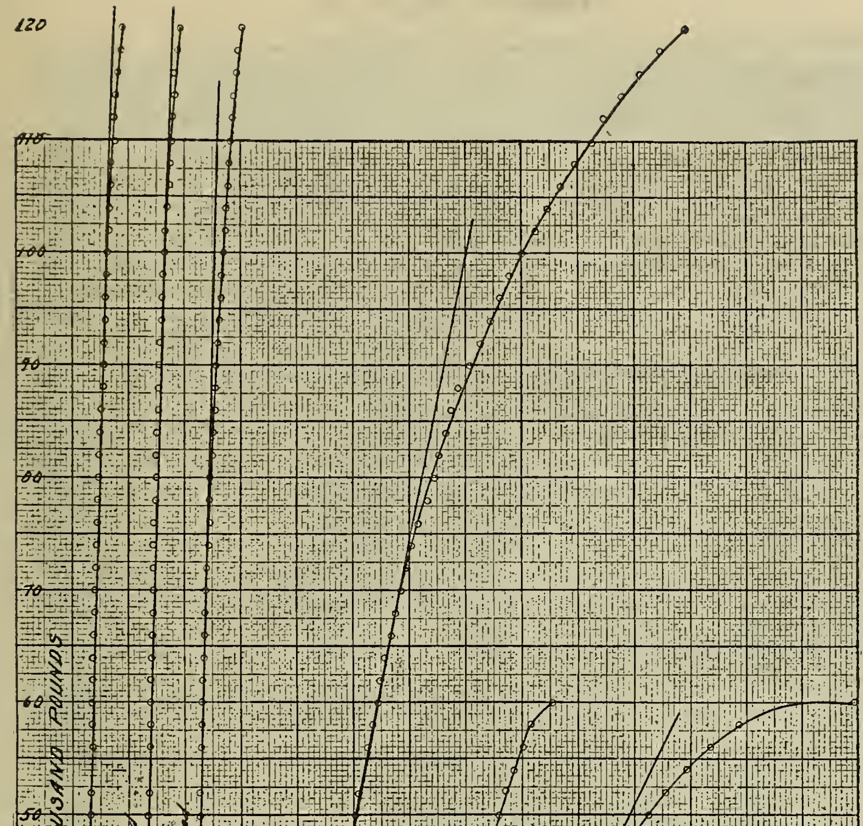


FIG. 24.—*Load-deformation curves, wheel No. 17*

TABLE 25.—Wheel No. 18

[Description—Rear wheel, 40 by 10 inches; cast steel; 7 hollow spokes; composite design. Weight—325 pounds. Chemical analysis (per cent)—Carbon, 0.33; sulphur, 0.058; phosphorus, 0.033; manganese, 0.72; silicon, 0.43]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	46 000
Maximum applied load in pounds	120 000
Deformation at maximum load in inches	0. 1230
Permanent set at maximum load in inches	0. 0676
Slope of curve No. 2 in pounds per inch	1 968 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	538
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	1. 66
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	9
8000 pounds	16
10 000 pounds	26
12 000 pounds	37
14 000 pounds	50
16 000 pounds	65
18 000 pounds	82
20 000 pounds	102

SIDE-THRUST TEST	
Proportional limit in pounds	35 000
Ultimate strength in pounds	82 300
Slope of curve in pounds per inch	93 200
Elastic resiliency in inch-pounds:	
At load	6560
180° from load	4900
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	20. 20
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	21
4000 pounds	86
6000 pounds	193
8000 pounds	343
10 000 pounds	536
12 000 pounds	772
14 000 pounds	1050
16 000 pounds	1374
18 000 pounds	1740
20 000 pounds	2146
Character of failure: Tension failure in hub near point of application of load.	

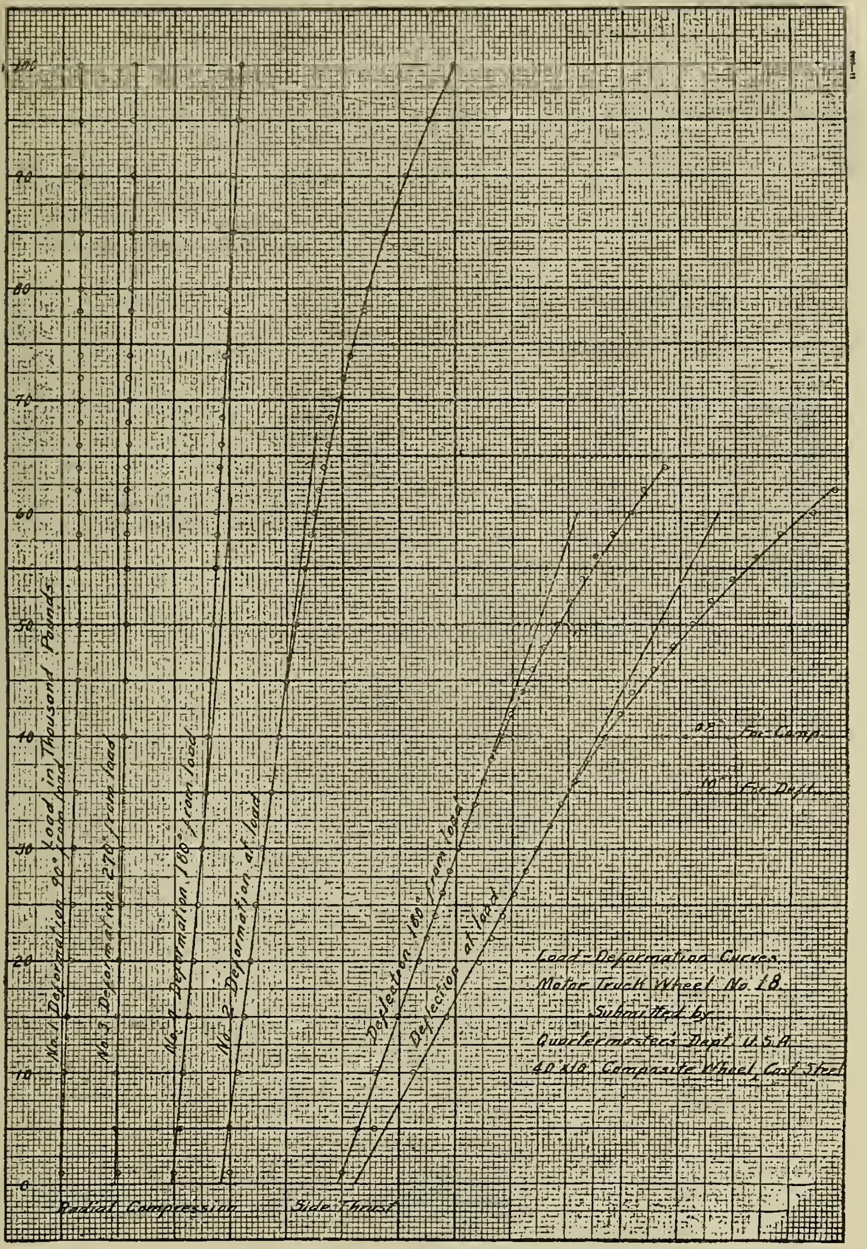


FIG. 25.—*Load-deformation curves, wheel No. 18*

TABLE 26.—Wheel No. 19

[Description—Rear wheel, 40 by 12 inches; cast steel; 7 hollow spokes; composite design. Weight—325 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.050; phosphorus, 0.048; manganese 0.36; silicon, 0.33]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	40 000
Maximum applied load in pounds	100 000
Deformation at maximum load in inches	0.1555
Permanent set at maximum load in inches.	0.1100
Slope of curve No. 2 in pounds per inch	1 836 000
Elastic resiliencies in inch-pounds:	
90° from load	195
At load	436
270° from load	94
180° from load	0
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	1.34
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	10
8000 pounds	17
10 000 pounds	27
12 000 pounds	39
14 000 pounds	53
16 000 pounds	70
18 000 pounds	88
20 000 pounds	109

SIDE-THRUST TEST	
Proportional limit in pounds	31 000
Ultimate strength in pounds	59 300
Slope of curve in pounds per inch	67 100
Elastic resiliency in inch-pounds:	
At load	7150
180° from load	7700
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	22.00
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	30
4000 pounds	119
6000 pounds	269
8000 pounds	477
10 000 pounds	745
12 000 pounds	1073
14 000 pounds	1460
16 000 pounds	1906
18 000 pounds	2413
20 000 pounds	2975

Character of failure: Tension failure in hub near point of application of load. Flaw in casting at point of failure.

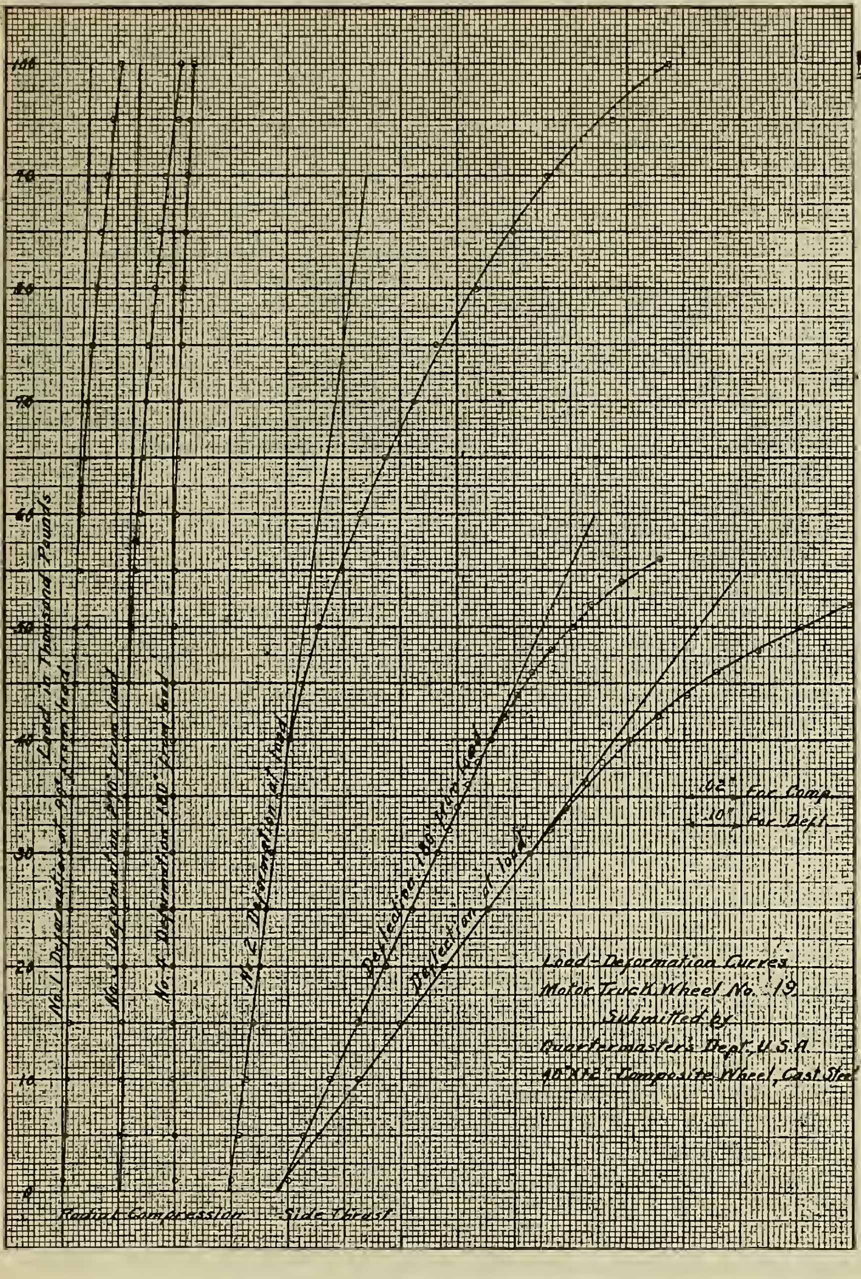


FIG. 26.—*Load-deformation curves, wheel No. 19*

TABLE 27.—Wheel No. 20

[Description—Front wheel, 36 by 5 inches; malleable iron; 7 hollow spokes; composite design. Weight—141 pounds. Chemical analysis (per cent)—Carbon, 2.58; sulphur, 0.056; phosphorus, 0.199; manganese 0.21; silicon, 0.722]

RADIAL-COMPRESSION TEST	
Proportional limit in pounds	43 500
Maximum applied load in pounds	60 000
Deformation at maximum load in inches	0.0741
Permanent set at maximum load in inches	0.0271
Slope of curve No. 2 in pounds per inch	926 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	1131
270° from load	
180° from load	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	8.02
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	4
4000 pounds	16
6000 pounds	33
8000 pounds	56
10 000 pounds	80
12 000 pounds	108
14 000 pounds	140
16 000 pounds	176
18 000 pounds	221
20 000 pounds	270

SIDE-THRUST TEST	
Proportional limit in pounds	12 500
Ultimate strength in pounds	25 300
Slope of curve in pounds per inch	45 400
Elastic resiliency in inch-pounds:	
At load	1718
180° from load	310
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	12.20
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	44
4000 pounds	176
6000 pounds	396
8000 pounds	705
10 000 pounds	1100
12 000 pounds	1584

Character of failure: Tension failure in hub at root of the two spokes under the load.

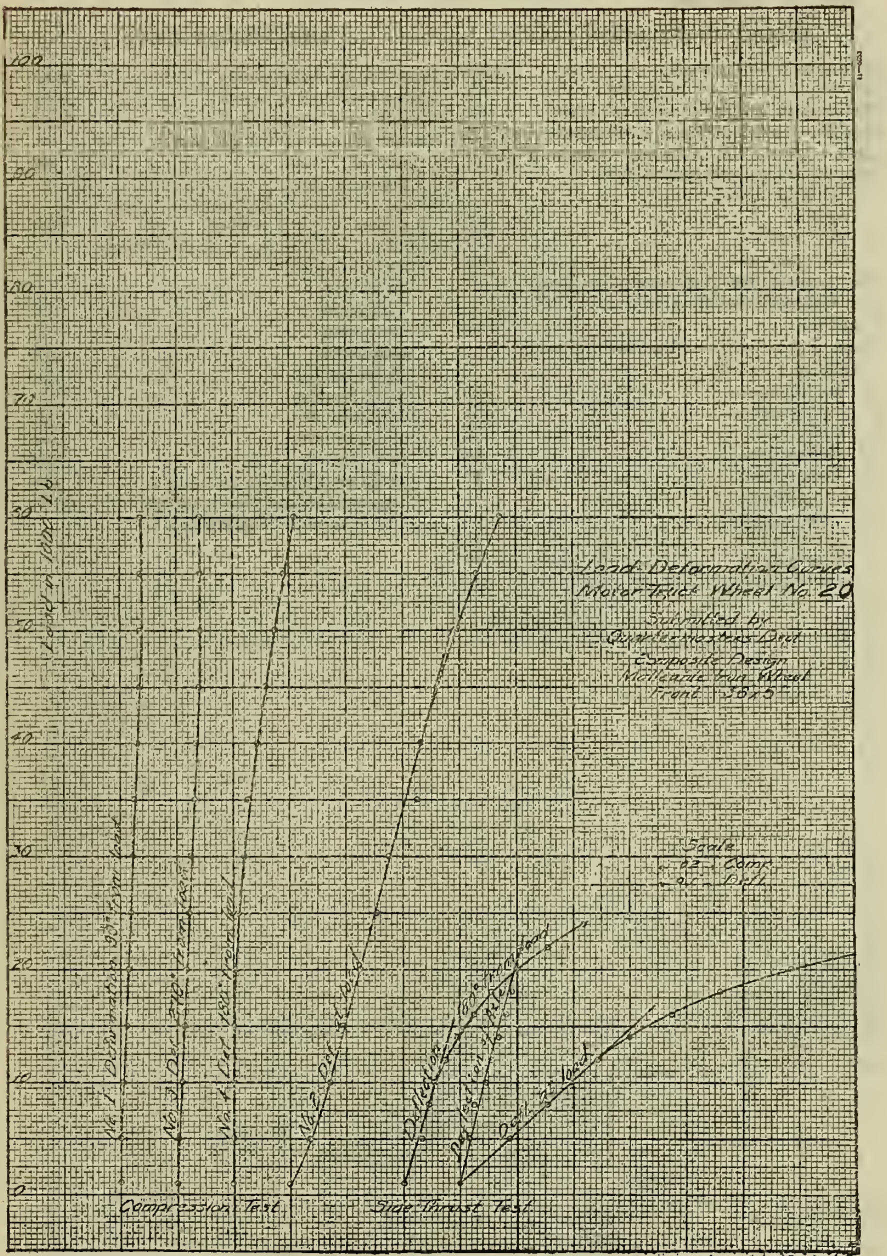


Fig. 27.—*Load-deformation curves, wheel No. 20*

TABLE 28.—Wheel No. 21

[Description—Rear wheel, 40 by 10 inches; malleable iron; 7 hollow spokes; composite design. Weight—288 pounds. Chemical analysis (per cent)—Carbon, 2.39; sulphur, 0.078; phosphorus, 0.199; manganese, 0.23; silicon, 0.980]

RADIAL-COMPRESSION TEST

Proportional limit in pounds	64 000
Maximum applied load in pounds	120 000
Deformation at maximum load in inches	0.1361
Permanent set at maximum load in inches	0.0715
Slope of curve No. 2, in pounds per inch	1 818 000
Elastic resiliencies in inch-pounds:	
90° from load	
At load	1128
270° from load	255
180° from load	450
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel	3.91
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	1
4000 pounds	4
6000 pounds	10
8000 pounds	18
10 000 pounds	28
12 000 pounds	40
14 000 pounds	54
16 000 pounds	70
18 000 pounds	89
20 000 pounds	110

SIDE-THRUST TEST

Proportional limit in pounds	28 000
Ultimate strength in pounds	55 400
Slope of curve in pounds per inch	69 600
Elastic resiliency in inch-pounds:	
At load	7280
180° from load	
Elastic resiliency in inch-pounds at load, per pound of metal in wheel	25.30
Resiliency in inch-pounds at point of application of load at—	
2000 pounds	70
4000 pounds	270
6000 pounds	555
8000 pounds	900
10 000 pounds	1300
12 000 pounds	1740
14 000 pounds	2240
16 000 pounds	2760
18 000 pounds	3380
20 000 pounds	4000

Character of failure: Tension failure in two spokes and in rim at point of application of load

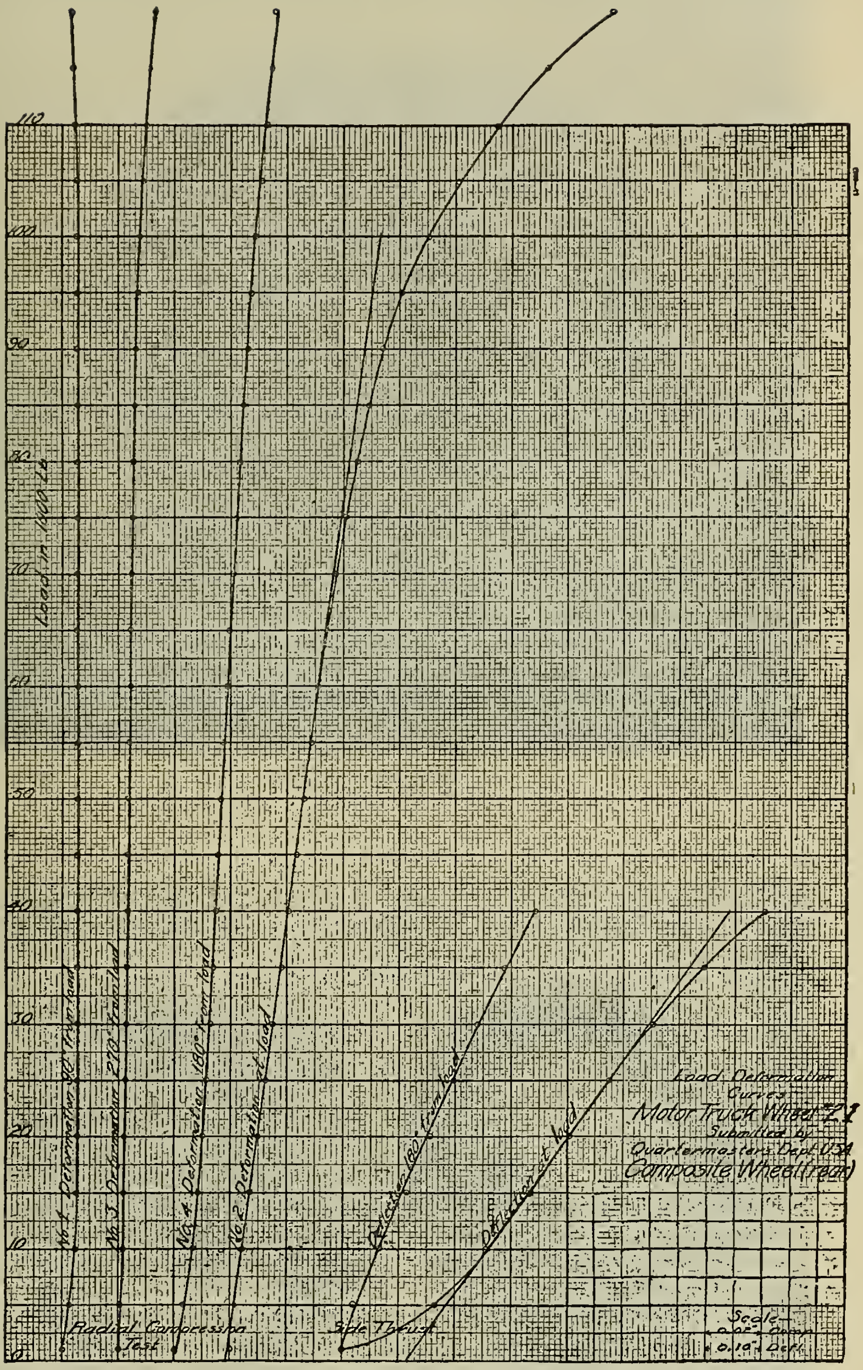


Fig. 28.—*Load-deformation curves, wheel No. 21*

Washington, July 11, 1919.

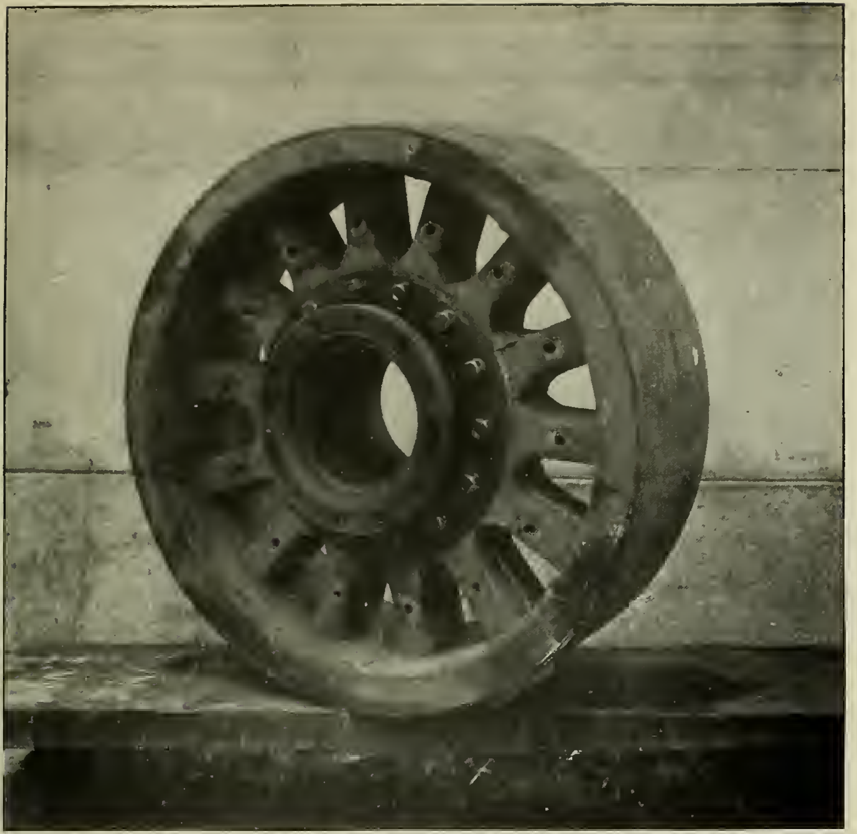


FIG. 29.—*Wheel No. 1*

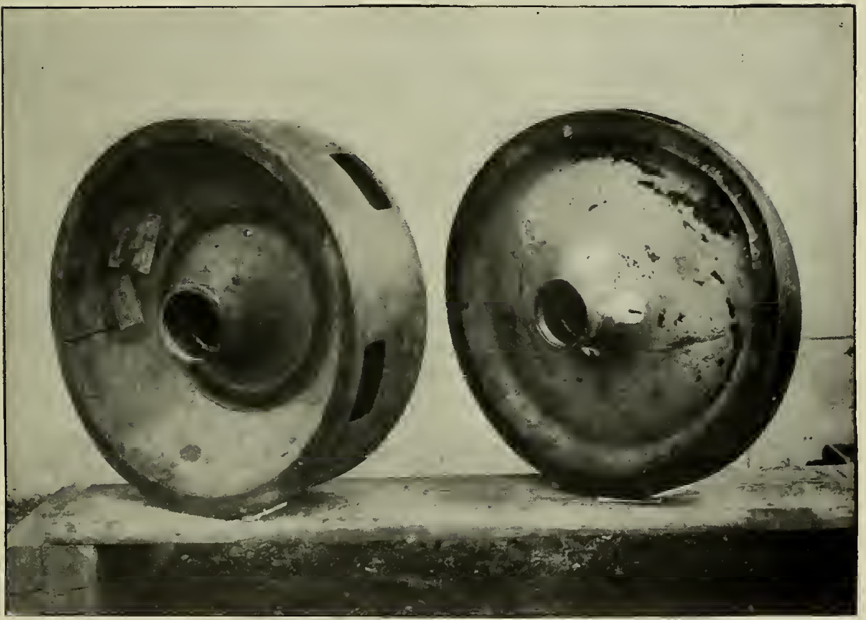


FIG. 30.—*Wheels No. 3 and 2*

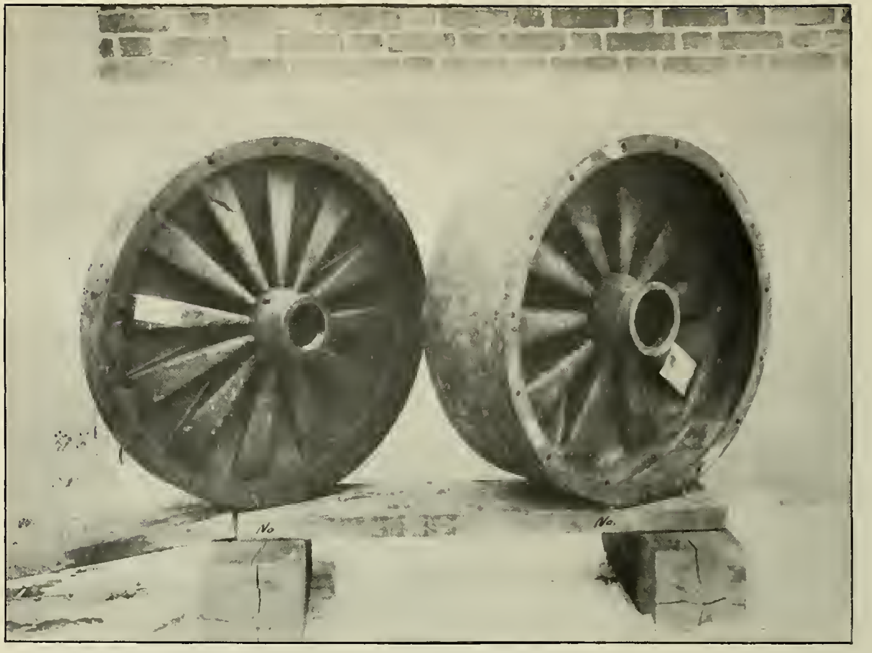


FIG. 31.—*Wheels No. 4 and 5*

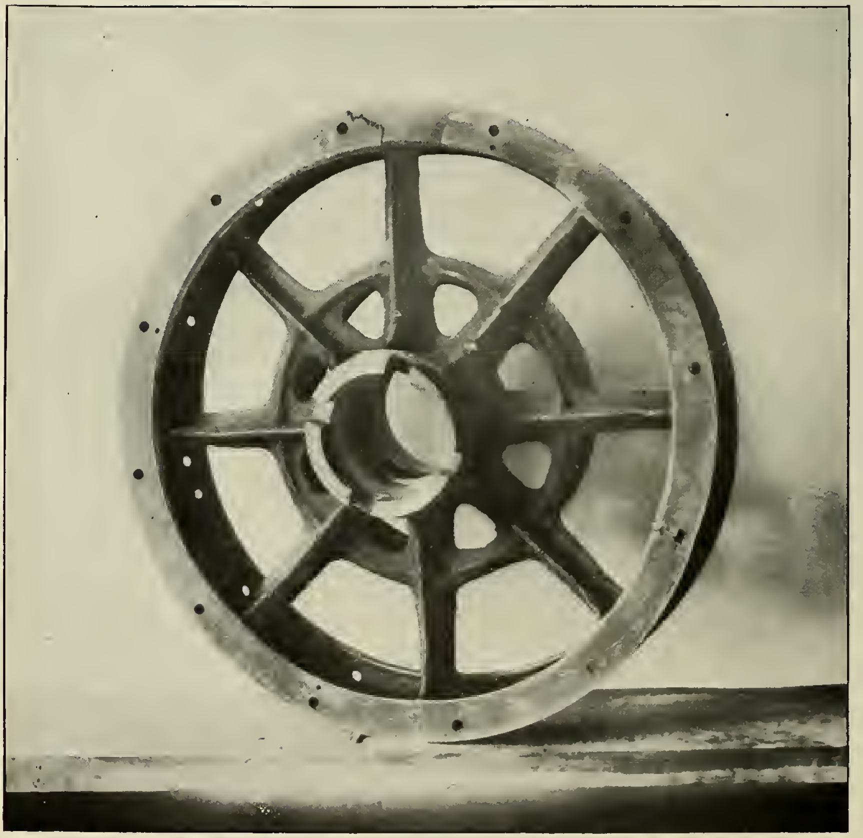


FIG. 32.—*Wheel No. 6*

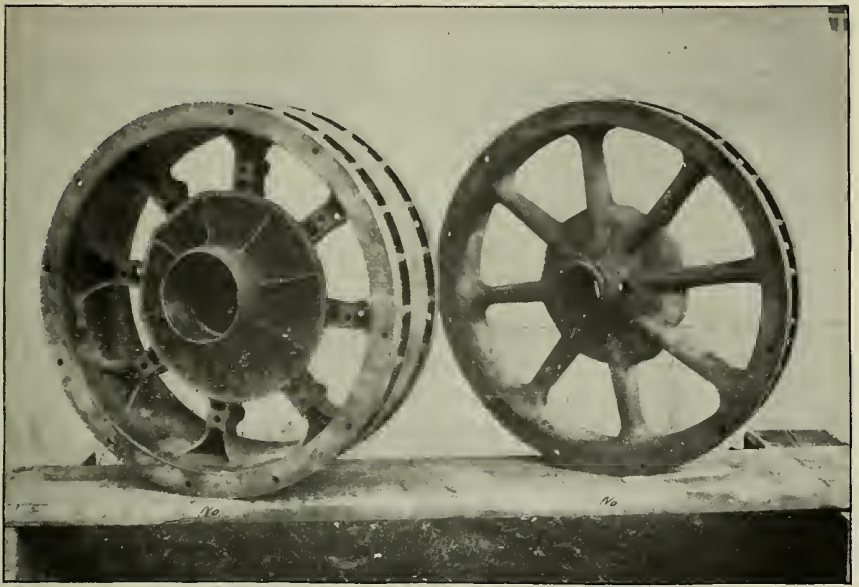


FIG. 33.—*Wheels No. 8 and 7*

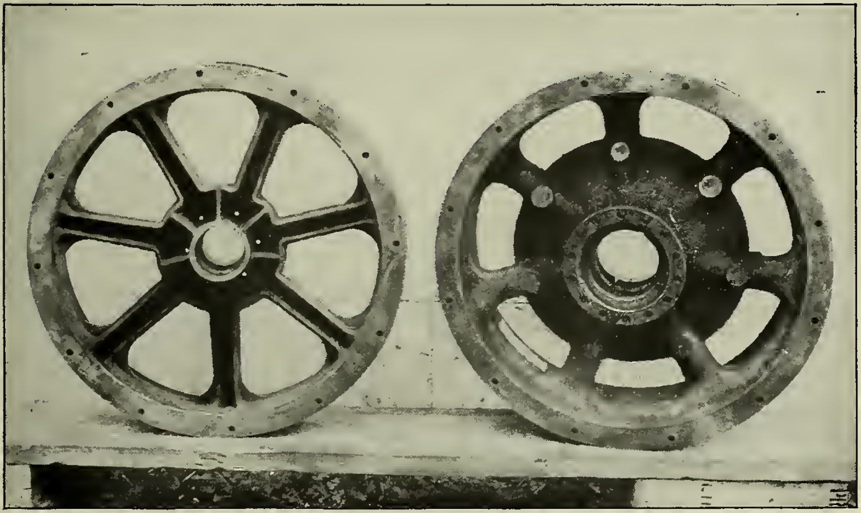


FIG. 34.—*Wheels No. 9 and 10*

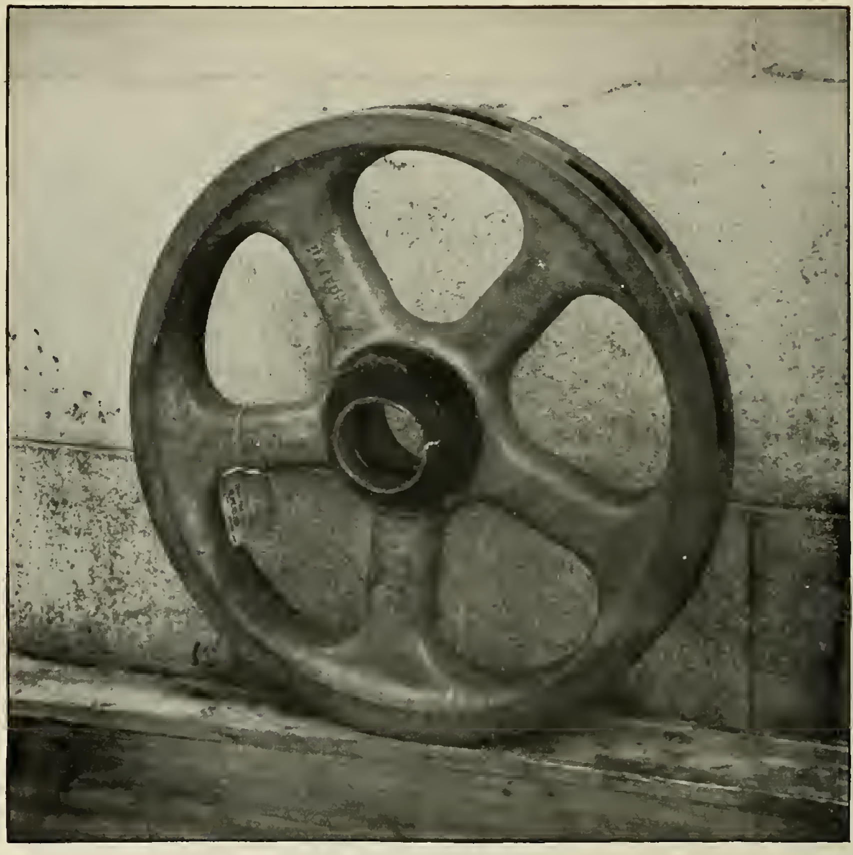


Fig. 35.—*Wheel No. 11*

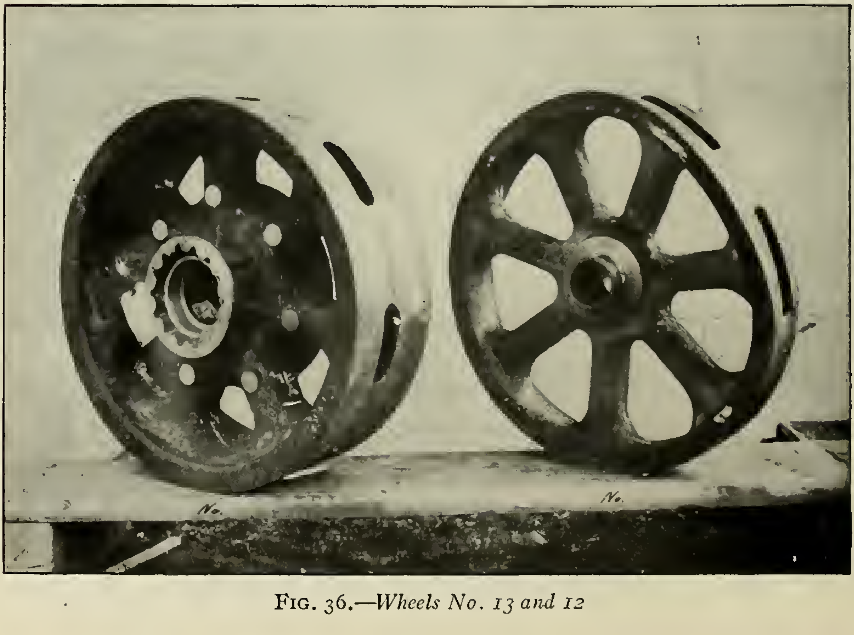


Fig. 36.—*Wheels No. 13 and 12*

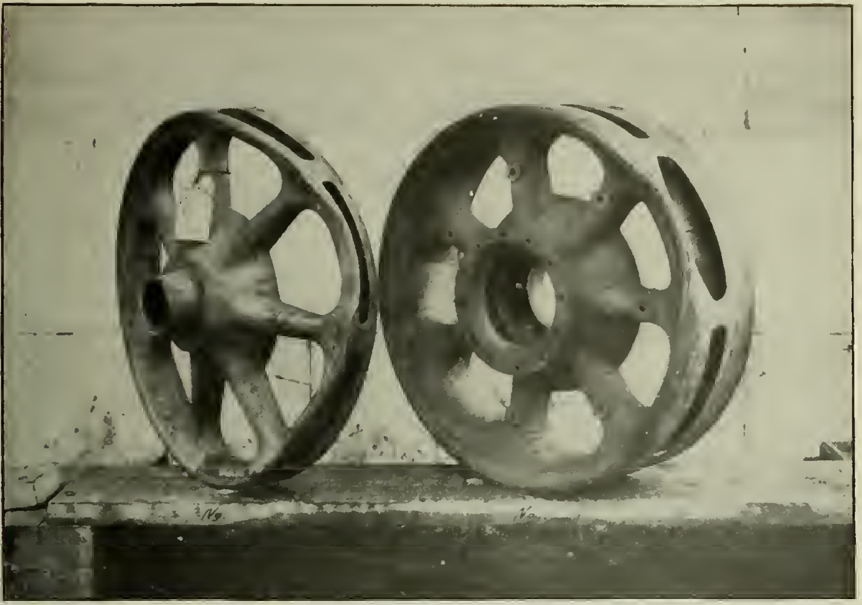


FIG. 37.—*Wheels No. 14 and 15*

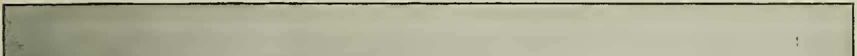


FIG. 38.—*Wheels No. 17 and 16*

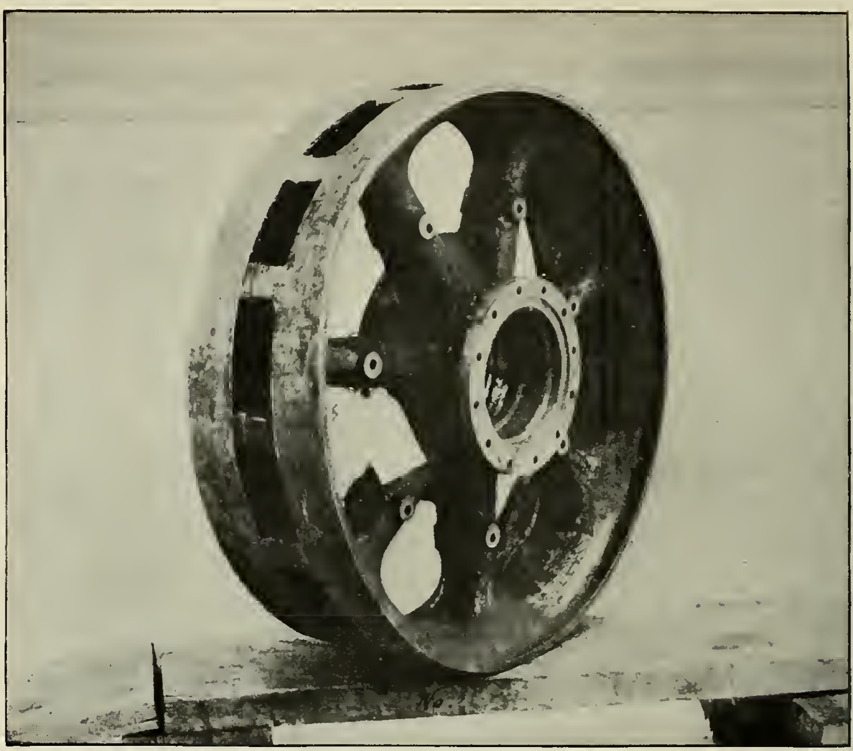


Fig. 39.—*Wheel No. 18*

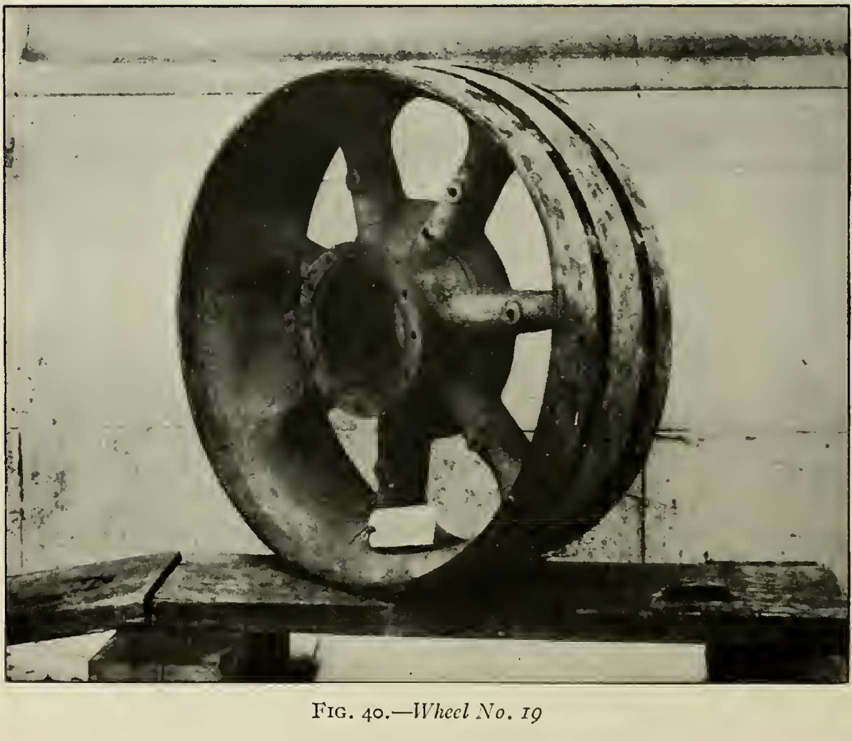


Fig. 40.—*Wheel No. 19*

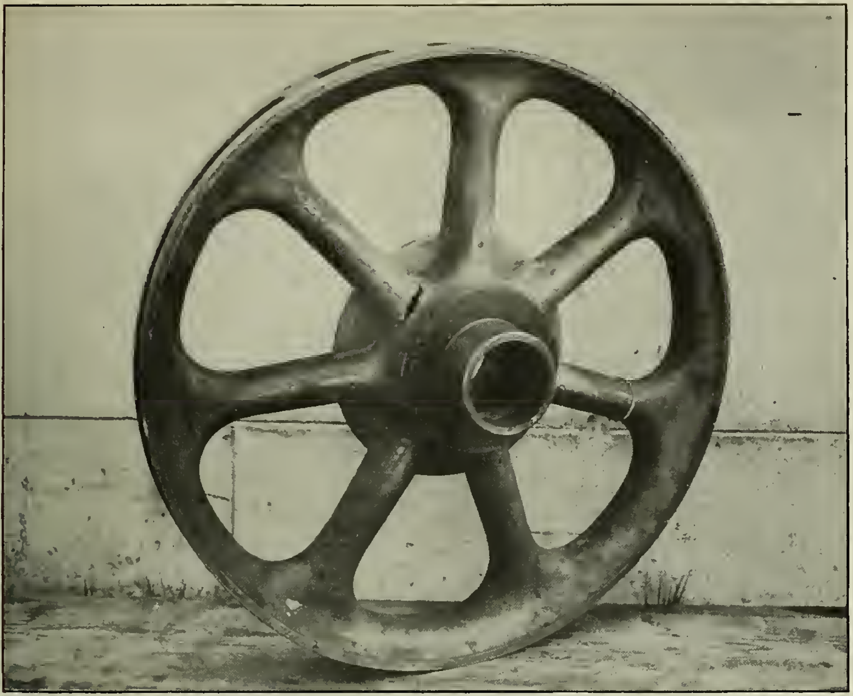


FIG. 41.—*Wheel No. 20*

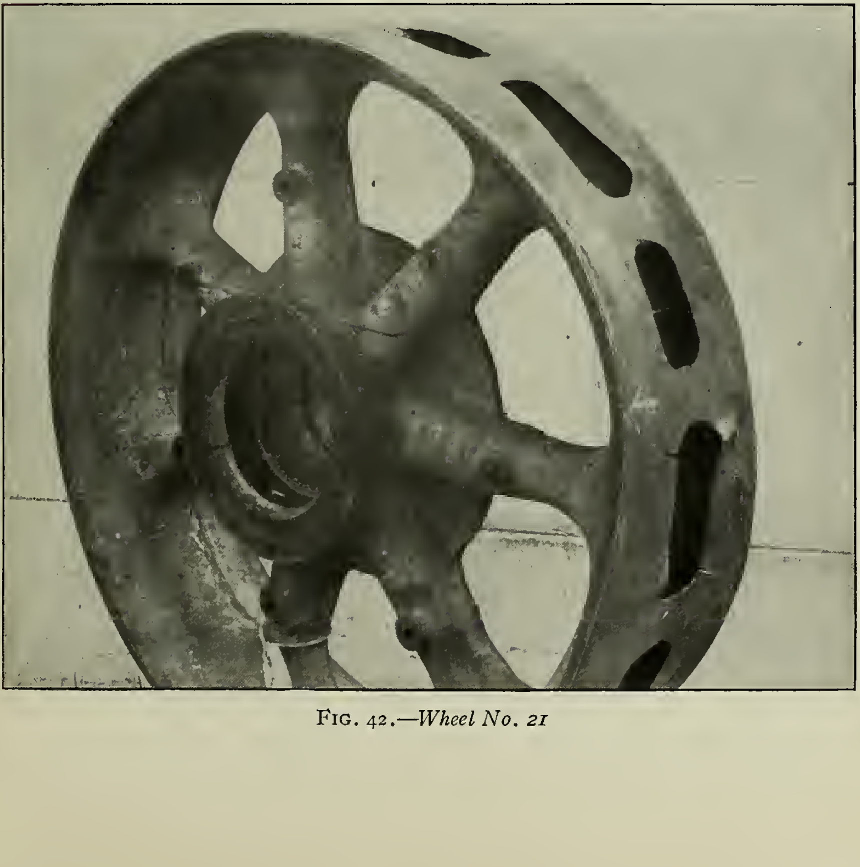


FIG. 42.—*Wheel No. 21*